BOSTON UNIVERSITY

GRADUATE SCHOOL

Thesis

"VIDEO-AMPLIFIERS."

by

Vaman S.Bawdekar

(B.Sc.,Bombay University,1945)

submitted in partial fulfillment of the

requirements for the degree of

Master of Arts

1948

Approval Page-

Approved by-

First Reader- Royal M. Frye
Professor of Physics,

Second Reader- W. Cullen Moore
Instructor in Physics,

"Contents"

"List of Illustrations."

Introduction

The main object of the present work on "Video-Amplifiers" is to collect the data on the subject matter available at the present time and to present it in a compact form. So, data is collected from various journals and text books and an attempt is made to compile this data in a logical and instructive manner.

The theme is the process of amplification of video signal used in reproduction of pictures in television system. In chapter II a short outline of the working of a television system is presented. Emphasis is placed on the production of video signal (the picture signal) and the construction and working of elements that go towards it. In chapters III and IV the video signal, (camera signal plus blanking and sync. pulses) is discussed and relative functions of D.C. and A.C. components of the camera signal are clearly pointed out.

In the case of television at work, generally some standard waveforms are used for comparison purposes. In order to clarify the utilization of these standard waveforms, for waveform distortion purposes, they are analysed briefly. At the same time, the most useful response analysis (transient response analysis) is discussed. It is found tobe useful in comparing all possible, periodic or non-periodic, output waveforms of the television system.

In the next three chapters, the problem of video amplification is considered. As will be seen from the discussion

a problem of video amplification is divided into two steps, H.F. and L.F. considerations. So the first two chapters, deal with the H.F. and L.F. considerations separately. In these chapters, the elements that disturb the response at the frequencies under consideration, and the circuits that improve the response, are discussed. In the last chapter, the two, H.F. and L.F. considerations are considered together and discussed. The effect of combining the H.F. and L.F. compensation in arbitrary fashion, is brought out clearly and the effective coupling is pointed out. A typical video amplifier stage with all compensation circuits applied, is diagramatized with all the requirements such as tubes, elements, and their suggested values listed in the final chapter on Findings and Conclusions.

The field of video amplification is a vast one and more possibilities are being discovered daily. Consequently, this paper can only hope to skim the surface of the tremendous proportions of a video amplifier, its actual design and functioning.

Chapter I...

"The Television & Its Working"

Television is a system which produces moving visual images by the transmission of electrical impulses.These electrical impulses produced by the scanning process and sent over the communication channel to the receiver tube are called video impulses or signal.(Video meaning "I see").This video signal band which enables the reproduction of a picture has a range from 60c.p.s. to 4m.c.p.s.The reproduction improves in detail as the upper limit of the band width is extended.This will be seen from the analysis of the video-signal.

A television set consists mainly of a transmission unit, a communication channel and a receiver set.The transmission unit consists of a sound system and a picture transmitter.Both of these subunits of the transmission unit are separated from eachother, Even then common antennae may be employed for the two subunits at the transmitter.(so also at the receiver .Besides a common r-f-amplifier and 1st detector may be used in the receiver.)

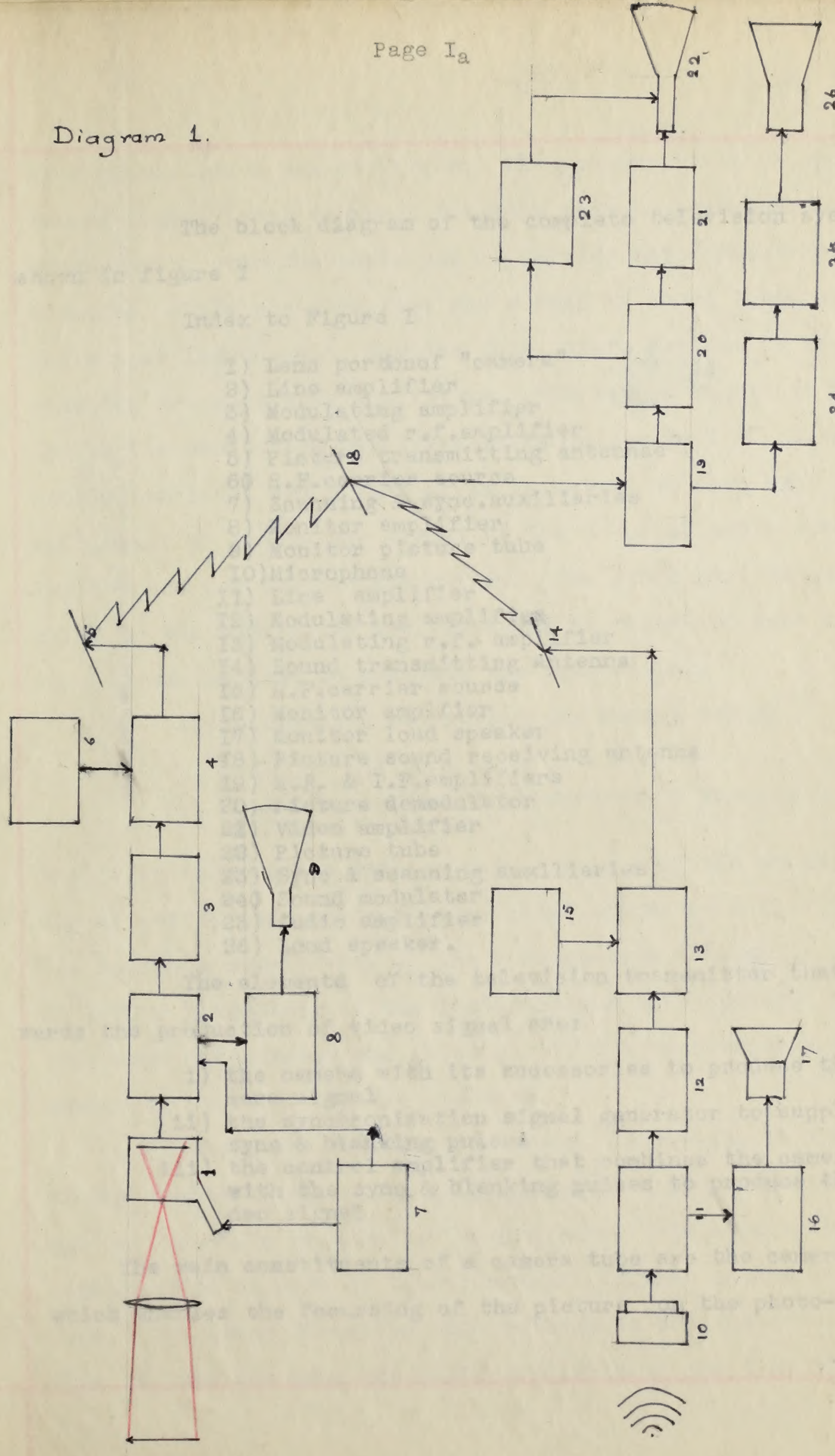
A picture transmitter consists of a camera tube with its synchronization circuits to generate the video signal,video amplifiers,r-f-amplifiers,a modulator ,U.H.F.carrier source and a radiator.While the receiver set consists of an rf.amplifier or detector,video amplifiers ,picture tube(Kinescope as it is popularly known) with its synchronization circuits,scanning generators and power supplies

(1a).

Diagram 1.

"Receiver".

"Transmitter"



" Block Diagram of Television System ".

(Radio-Engineering Handbook - Henney.)

The block diagram of the complete television system is shown in figure I

Index to Figure I

I) Lens portionof "camera"
2) Line amplifier
3) Modulating amplifier
4) Modulated r.f.amplifier
5) Picture transmitting antennae
6) R.F.carrier source
7) Scanning & sync.auxiliaries
8) Monitor amplifier
9) Monitor picture tube
IO)Microphone
II) Line amplifier
I2) Modulating amplifier
I3) Modulating r.f. amplifier
I4) Sound transmitting antenna
I5) R.F.carrier source
I6) Monitor amplfier
I7) Monitor loud speaker
I8) Picture sound receiving antenna
I9) R.F. & I.F.amplifiers
20) Picture demodulator
21) Video amplifier
22) Picture tube
23) Sync & scanning auxiliaries
24) Sound modulator
25) Audio amplifier
26) Loud speaker.

The elements of the television transmitter that go towards the production of video signal are:

i) the camera with its accessories to produce the camera signal
ii) the synchronization signal generator to supply the sync & blanking pulses
iii) the control amplifier that combines the camera signal with the sync & blanking pulses to produce the video signal

The main constituents of a camera tube are the camera lens which enables the focussing of the picture on the photo-sensi-

tive plate, and a pre-amplifier. The pre-amplifier raises the camera signal level to about 0.1 volt peak-to-peak thereby its transmission over the cable can be carried out without interference. (This pre-amplifier has a gain of about 1,000 with low output impedance.) Besides this, there are one or more scanning generators or amplifiers. The camera signal is then, fed to the monitoring amplifier which raises part of it to the monitoring level and a part of it is raised to the level just sufficient to supply the signal to the co-axial cable connecting the monitor to the transmitter. The other part is supplied to the modulating amplifier and is raised to such a level that it can be used to modulate the transmitter.

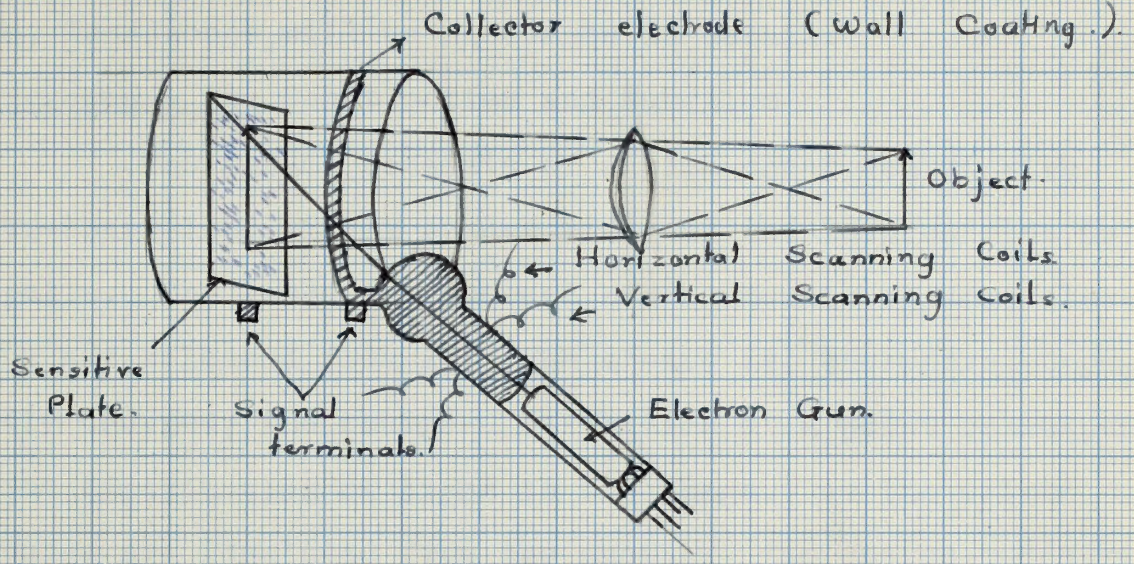
Classification of present day camera tubes:

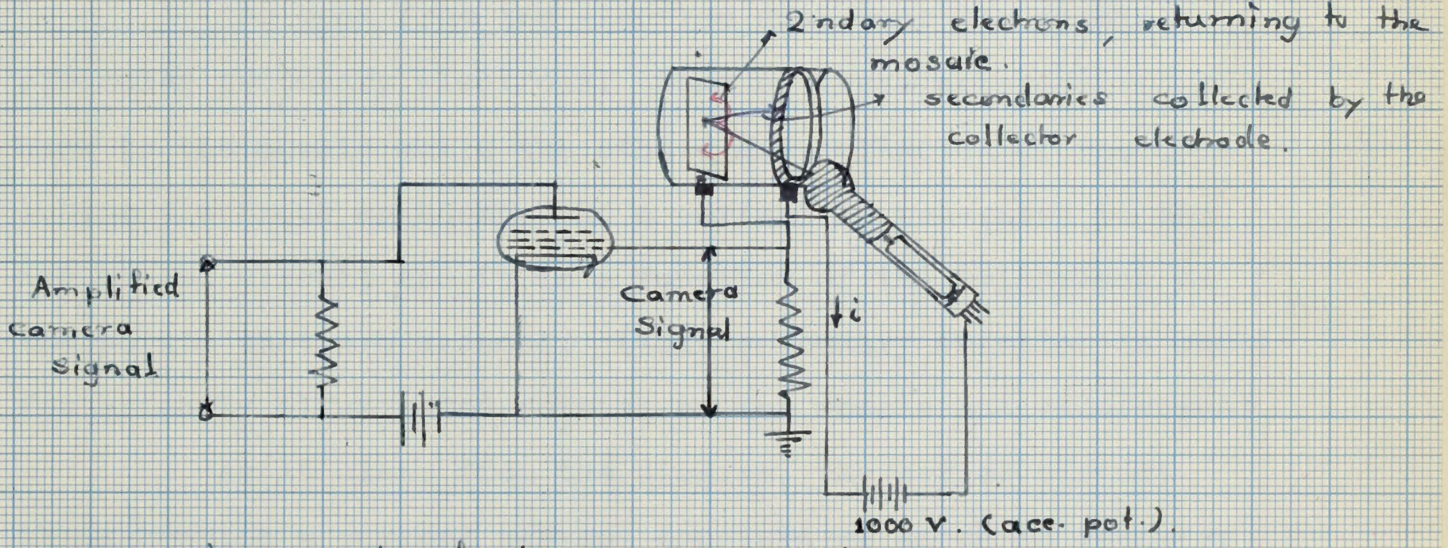
1) Iconoscope
2) Image Orthicon
3) Image Iconoscope (Iconotron or Superemitron)
4) Image dissector

The first three tubes work on the principle of the storage, the effect of the incident light being stored as a charge. The luminous sensitivity of the storage-type devices is 10,000 to 100,000 times that of the instantaneous type devices, depending upon the storage and photo-electric efficiencies and the number of picture elements produced.

Among the storage type tubes, Iconoscope is the most widely used although the Image Orthicon has higher sensitivity and on the whole is a better camera tube. Its working and construction is more or less identical to that of the Iconoscope. The image dissector tube belongs to the instantaneous type of tube and uses the light available at the time of scan-

Diagram 2 "Iconoscope".





i = current of collected 2ndary electrons.

Sensitivity under optimum conditions.
1 m.v. per millilumen per cm², illumination of the mosaic, at low illumination to 0.25 m.v. at high illumination.

(Principles of Television Engineering. Fink.).

ning. It is generally used in televising motion picture film where the light source is brilliant and highly concentrated. Here, Iconoscope will be discussed in detail.

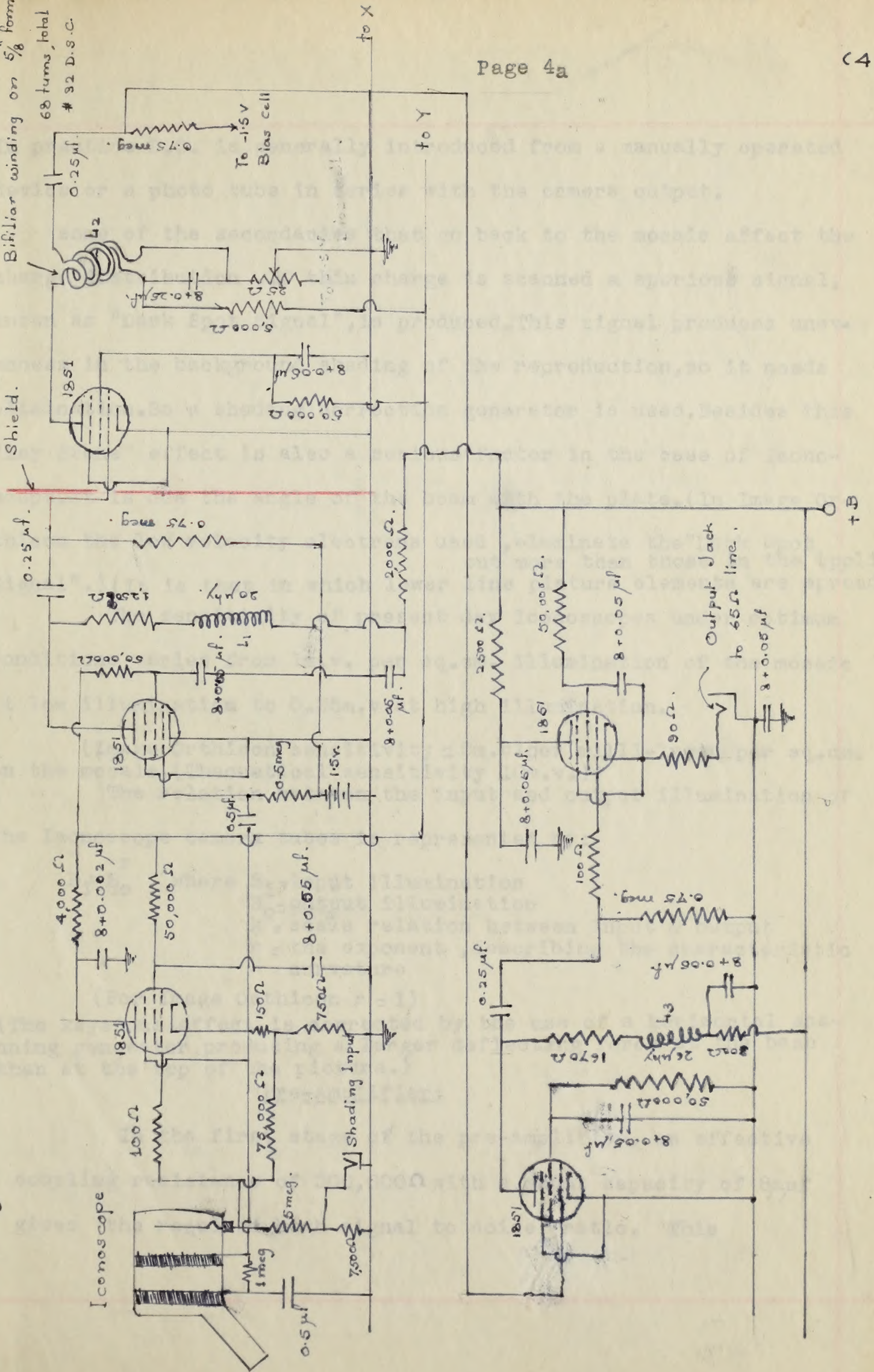
<u>Iconoscope</u> - its Construction and Function

The mosaic consists of a mica-sheet coated with photo-sensitized silver on one side and the reverse side is of graphite. The image is focussed on the mosaic so some electrons are released from it. The mosaic is, therefore, positively charged; the charge-distribution at a point corresponds to the distribution of light in the image. As the silver globules are insulated from one another, the charge-redistribution is prevented. So the charge increases in magnitude as long as light strikes the mosaic.

The beam from the electron gun scans the mosaic producing secondary electrons. Some of these secondaries go back to the mosaic while the others are collected by the collector electrode as shown. So a current is generated in the associated circuit and it is a function of the brightness of the points that are scanned. (This secondary emission is small for brightly illuminated portion of the mosaic and vice-versa).

As is clear from the diagram, the series circuit through which a current passes, consists of an ohmic resistor of the secondary emission path, the coupling resistor and the capacitance between the graphite side of the mosaic and the group of silver globules under the scanning spot. The D.C. component of this current is not passed through this capacity therefore, the output is mainly the A.C. component of the camera signal.

Diagram. 3. Iconoscope Preamplifier (After Barco.)



In practice D.C. is generally introduced from a manually operated device or a photo tube in series with the camera output.

some of the secondaries that go back to the mosaic affect the charge distribution .If this charge is scanned a spurious signal, known as "Dark Spot Signal",is produced.This signal produces unevenness in the background shading of the reproduction,so it needs elimination.So a shading correction generator is used.Besides this "Key Stone" effect is also a serious factor in the case of Iconoscope.It is due the angle of the beam with the plate.(In Image Orthicon the low velocity electrons used ,eleminate the"Dark Spot Signal".)(It is that in which lower line picture elements are spread out more than those in the topline.

The sensitivity of present day Iconoscopes under optimum conditions varies from Im.v. per sq.cm. illumination of the mosaic at low illumination to 0.25m.v.at high illumination.

(Image Orthicon sensitivity = 2m.v.per milli-lumen per sq.cm. on the mosaic,(Theoretical sensitivity IOm.v.))

The relation between the input and output illumination of the Iconoscope camera tubes is represented by:

$B_i = B_o^r$ where B_i = input illumination
B_o = output illumination
k = scale relation between input & output
r = the exponent ,describing the characteristic curvature

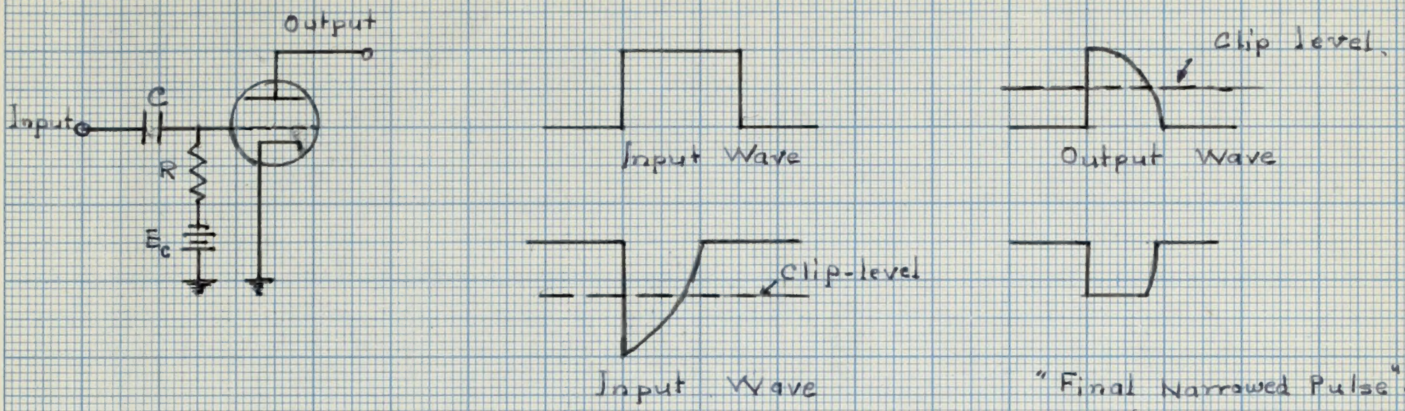
(For Image Orthicon r = I)

(The keystone effect is corrected by the use of a horizontal scanning generator producing a larger deflecting force at the base than at the top of the picture.)

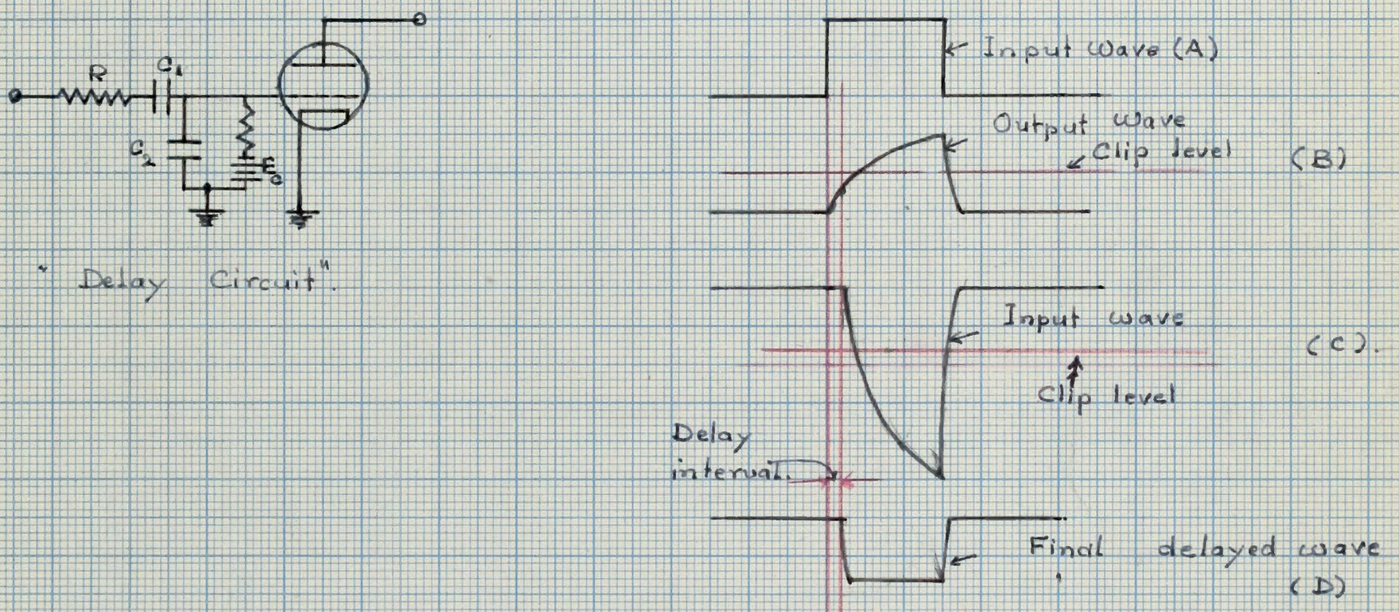
Pre-Amplifier;

In the first stage of the pre-amplifier, an effective coupling resistance of 300,000Ω with a shunt capacity of 8μμf gives the required high signal to noise ratio. This

Diagram 4



(The narrowing function in a Wave shaping circuit. The initial Sq.wave is passed through the differentiating circuit (RC-circuit) and clipped. Then the portion above the clip level is amplified and clipped again. The final pulse is thus narrowed but not delayed.)

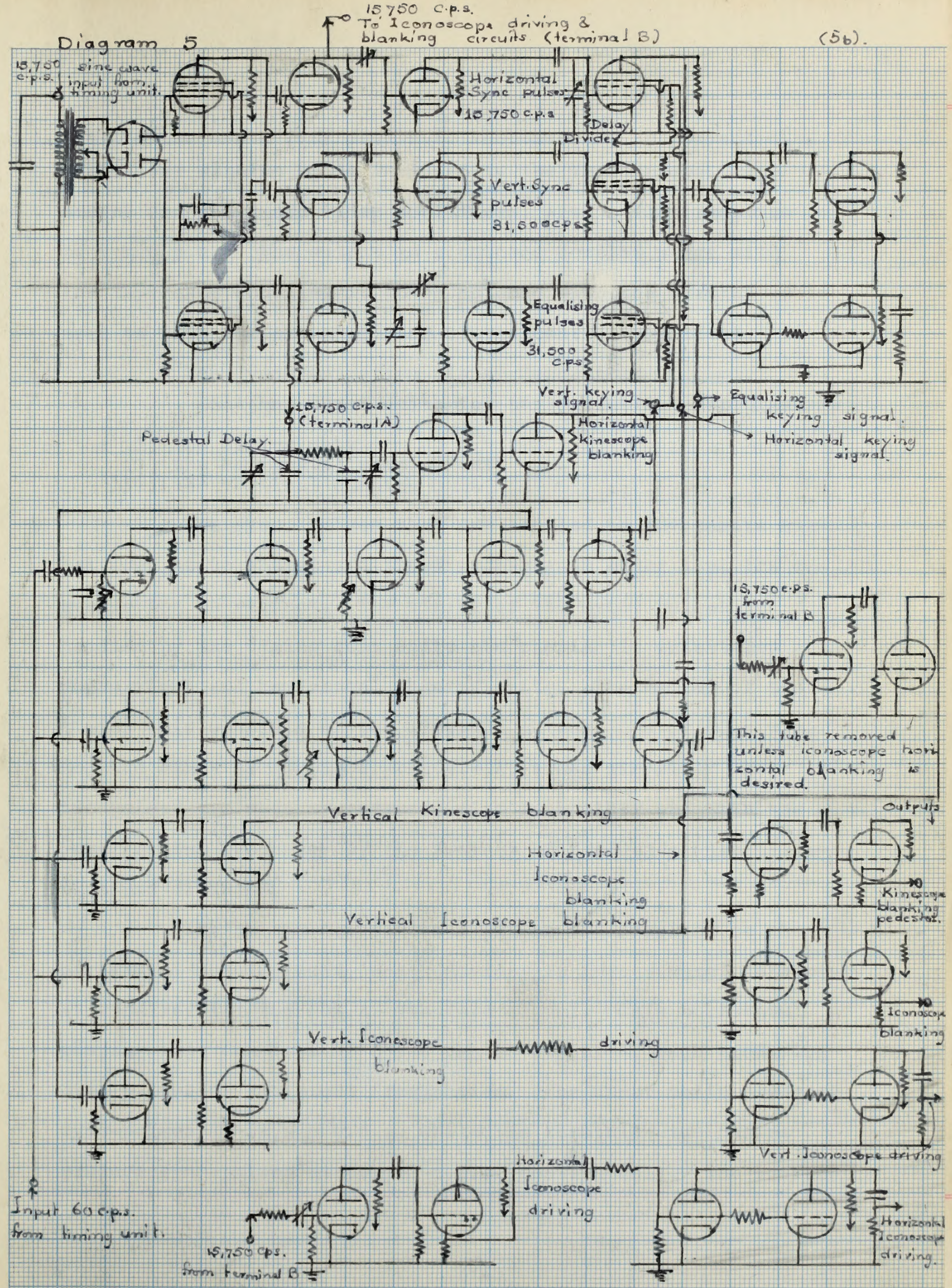


(The delay function in Wave-shaping Circuits. The delay circuit produces a curved wave (B) from the initial sq. wave (A) The curved wave is clipped and portion above the clip level is amplified, and reclipped. The resultant delayed wave (sq. wave) is shown in D..).

(Principles of Television Engineering _ Fink.).

" Wave Shapes".

Diagram 5 (5b).



"Horizontal & Vert. Shaping Units" (Prin. of Television Eng. - Fink).

combination has a very poor H.F. response, so to correct this, a bifiliar winding L_2 is included in the third stage. The seoond and third stages are video amplifiers, with a flat response to 5 m.c.p.s. The output is a cathode coupled stage with low impedance enabling it to be matched with the coaxial cable used to join the pre-amplifier to the control amplifier.

The Synchronization Signal Generator:

It has three units for three distinct performances

i) the timing unit
ii) the horizontal shaping unit
iii) the vertical shaping unit

The sync. pulses that are applied to the camera signal need to be shaped and timed properly in order that the reproduction be perfect. The timing of the sync. pulses is handled by the timing unit while the shaping is undertaken by the vertical and horizontal shaping units. The output of the timing unit consists of two distinct pulses, one at 60 c.p.s. and the other at 15,750 c.p.s.(R.M.A. video signal.) These two pulses are made synchronous with each other and with the power system frequency by the process of frequency multiplication and division.

The 15,750 c.p.s. timed pulses are supplied to the horizontal shaping unit, which divides it into several wafeforms as required for the R.M.A. standard signal. This horizontal shaping unit consists of three chains of tubes, each producing sync-pulses of different frequencies. The upper chain produces sync-pulses at 15,750 c.p.s. while the remaining two chains produce sync-pulses at 31,500 c.p.s. continuously. The succes-

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sive tubes in the chains are used to shape the pulses and to obtain the required steepness. These three pulses from three chains are interspersed and after being amplified by the remaining stages of the unit are fed to the mixing amplifier.

The other output of the timing unit is fed to the vertical shaping unit, which produces keying signals at 60c.p.s. Besides the keying signals, two types of blanking signals are obtained from this unit, during the retrace period.

Two types of Blanking Signals:

i) One for composite video-signal-horizontal and vertical waves at 15,750 c.p.s.

ii) Second for the control of the scanning beam in the camera tube - vertical and horizontal waves at 60c.p.s.

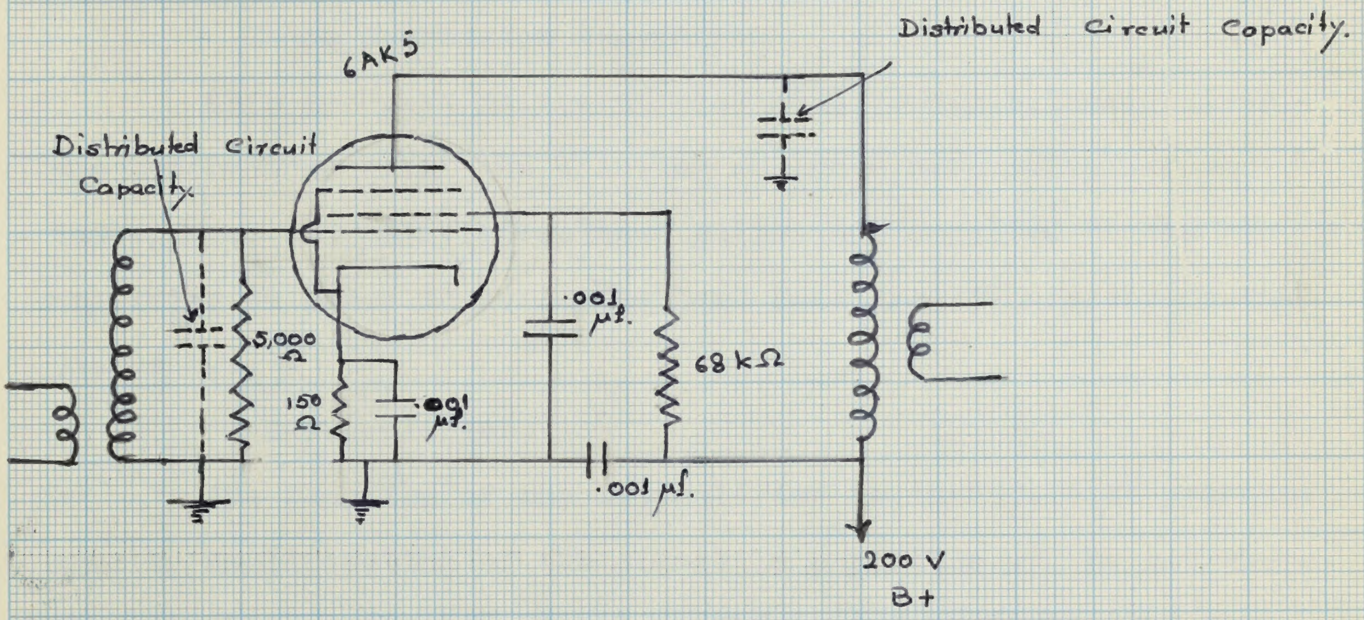
The keying signals produced by the vertical shaping unit are supplied to the screen grids of the keying tubes in the horizontal shaping units. Thus the passage of the horizontal sync pulses is controlled.

Mixing Amplifier:

All the pulses - camera pulses, sync. pulses, both vertical and horizontal, and blanking signals - are supplied to the input terminals of this amplifier. The camera and blanking signals are mixed first by means of two amplifiers, feeding a common load-resistor across which sync. pulses are applied. The D.C. component of the video signal so formed, is controlled by the voltage on the blanking signal tube.

The combination of the sync. pulses, applied to a common load resistor mentioned above, and the first two pulses,

Diagram 6



"A Typical Television R.F. Amplifier"

(Television Simplified – Kiver.)

is carried in two stages ,with a common load resistor.If the bias aco across these tubes of these stages is maintain-ed at aproper value,the 75to25% relationship between the camera & sync.pulses' amplitudes required by the std. video signal,is obtained.

Shade Correction Generator:

This produces pulses at 60c.ps&15,750c.p.s.These pulses are synchronous with the scanning motion & have cotrolled amplitudes,phases and polarities.These pulses are supplied to the pre-ampli amplifier in order to avoid the"Dark Spot Signal",present in the Iconoscope.

R-F-Amplifier:

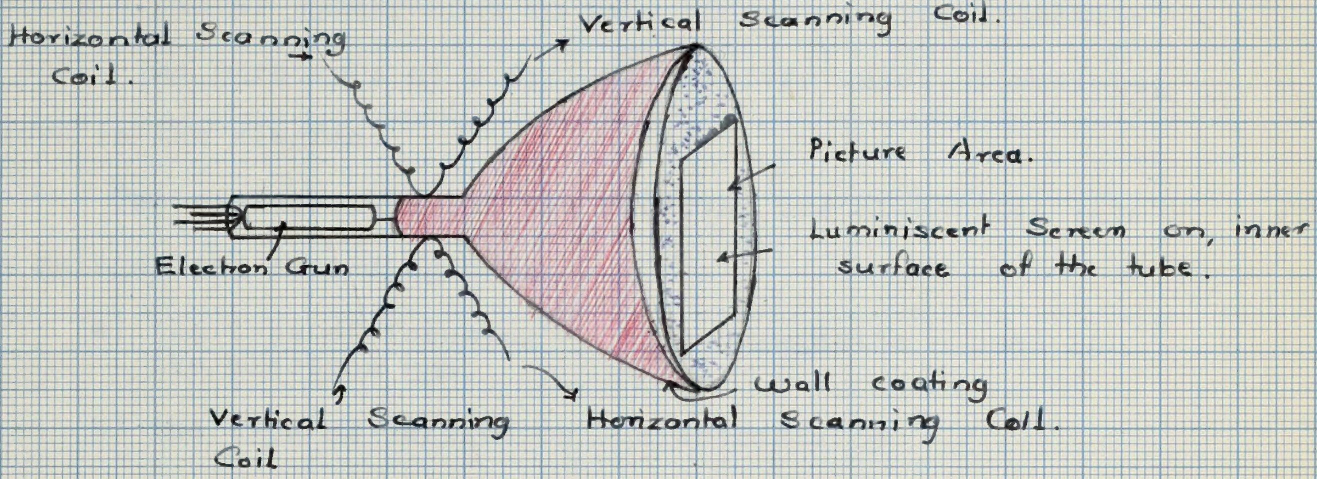
The function of ther.f.amplifier is threefold.It produces greater amplification of the signal in a portion of the set where the signalis at its lowest value.(This extra amplification is a deciding factor in the noisy locations,)Secondly it provides greater discrimination against signals inthe adjacent bands,particularly applicable for image frequencies.Finally a properly designed R.F. stage eliminates any interference that may be in the tubes themselves. Theseinternal disturbances appear as white spots ,in a television system system,if the r.f.amplifier is absent.

A typical television r.f.amplifier is shown in the diagram

Communication Channel:

The video signal from the mixing amplifier is carried along the communication channel to the receiver tube.In the communication chammel to the receiver tube.In the communication channel it is amplified & modulated to satisfy the req-uirements.The channel consists of a chain of video- amplifie-rs,radio transmitter,etc.

Diagram 7:



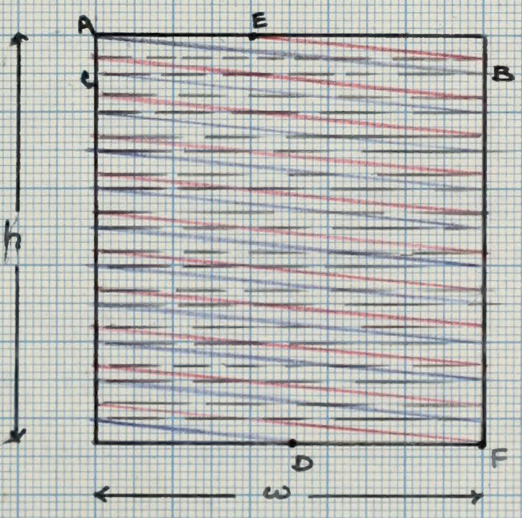
"Kinescope or Picture Tube".

(Radio Engineering Handbook - Henney.)

Diagram 8

Solid Coloured lines for actual scanning

Dotted lines for beam retraces.



Aspect Ratio = $\frac{w}{h}$.

A = start of field 1.
E = start of field 2.

D = end of field 1.
F = end of field 2.

"Interlaced Scanning pattern"

(Television Simplified - Kiver.)

This re-amplified and modulated video signal is supplied to the receiver tube scanning spot which traverses the screen in a manner synchronous to that of spot at the transmitting end. The structure of a typical receiver tube , kinescope, is shown in the diagram.

The picture tubes of the receiver are classified into three categories, depending upon:

a) the type of focusing - electromagnetic - used in the electron gun,

b) the type of deflection - electrostatic

c) the type of fluorescent coating and the color of emitted light.

The electron gun of the picture tube requires a power supply to produce the necessary electron beam for scanning purposes. This power supply may be either:

i) High voltage sources for the first and second anodes that draw electrons from the gun and focus the beam (electrostatically focused tubes)

ii) Heater current source for the cathode of the electron gun.

iii) Focusing coil current source for magnetostatically focused tubes.

The Scanning Process and its Related Terms;

It is the process by means of which camera signals are produced and consists of the periodically repeated path of the scanning spot, the electron beam, until the complete picture is covered. The electric signal, supplied to control the beam density is such that it indicates the brightness of a point of the picture at the position of the beam. The scanning pattern

can have any form, most generally used being a set of parallel lines. Sometimes interlaced scanning is used with advantage to avoid flicker in the reproduction.

The interlaced scanning consists in the motion of the spot in two series of lines, alternately passing downwards as shown. The scanning spot starts at A and goes along the blue lines to D; the retrace from points like B to points like C is brought about by the blanking signal. When D is reached, blanking signals are applied and the point is brought to E. From E the point starts moving along the red lines until the point F is reached and the picture is completely scanned. The dotted lines represent the inactive lines as they do not go towards the reproduction at all. While the blue and red lines are called "the active lines".

The number of these active lines in a scanning pattern is given by the formula:

$$n_a = \frac{n}{1 + \frac{1}{k_v}}$$

where n = no. of lines per frame

k_v = vertical retrace ratio

$= \frac{\text{upward scanning velocity}}{\text{downward scanning velocity}}$

Similarly, the horizontal retrace ratio (k_h) is defined as:

$$k_h = \frac{\text{backward scanning velocity}}{\text{forward scanning velocity}}$$

The values of k_h and k_v vary from 7 to 10 and 10 to 15 respectively. (R.M.A.) standards are : $k_h = 7$ lower limit

$k_v = 12$ lower limit

Vertical Resolution of a Scanning Pattern (r_v):

It is defined as the number of picture elements that can be accommodated in the vertical height of the picture area.

(Reference : Nos. 3 & 4)

As seen above, every active line is capable of reproduction but sometimes it may happen that the picture elements do not fall directly on the scanning lines. So the number of active picture elements that can be accommodated in a vertical direction is less than the number of active lines.

Therefore the vertical resolution (r_v) is given as:

$r_v = k n_a$ elements per picture heights.

where k = utilization factor
= 0.6 to 0.9
n_a = no. of active lines.

(In properly operated equipment $r_v = 400$ is commonly reached).

Horizontal Resolution of Scanning Pattern (r_h) :

It is the number of picture elements that can be accommodated in the horizontal direction in the width (w) of the picture. The horizontal resolution (r_h) depends upon the electrical performance of the television system in reproducing the rapid changes of voltage whereby the reproducing spot changes its brilliancy as it moves along each line. In terms of maximum frequency (f max.) of the video signal band considered the horizontal resolution (r_h) is given as:

$r_h = 84 f_{max.}$ elements per picture width

f_{max} is in mega-cycles, assuming the rate of 30 $\frac{\text{frames}}{\text{sec.}}$ and 525 lines. (For 441 lines, $r_h = 100 f_{max.}$)

The ratio (m) of the resolutions in two directions:

$$m = r_h / r_v = 84 f_{max.} / k n_a .$$

m need not be a unity necessarily. At present m is taken to be equal to 0.95 depending upon the max. frequency of the video signal for $f_{max} = 4.0$ m.c.p.s.

(Reference : No. 3,4,5)

and $n_a = 485$ lines,

$k = 0.75$

$m = 0.925$.

gives a good reproduction.

Aspect Ratio of the Scanning Pattern:

It is defined as the ratio of the width (w) to the height (h) of the rectangle, actively employed in the reproduction and gives a perfect reproduction if it equals 4:3 $\therefore$ for satisfactory reproduction: $w : h = 4 : 3$

(Adopted by F.C.C. for commercial television in July 1941).

(Ref: 1, 3, 4)

Diagram. 9.

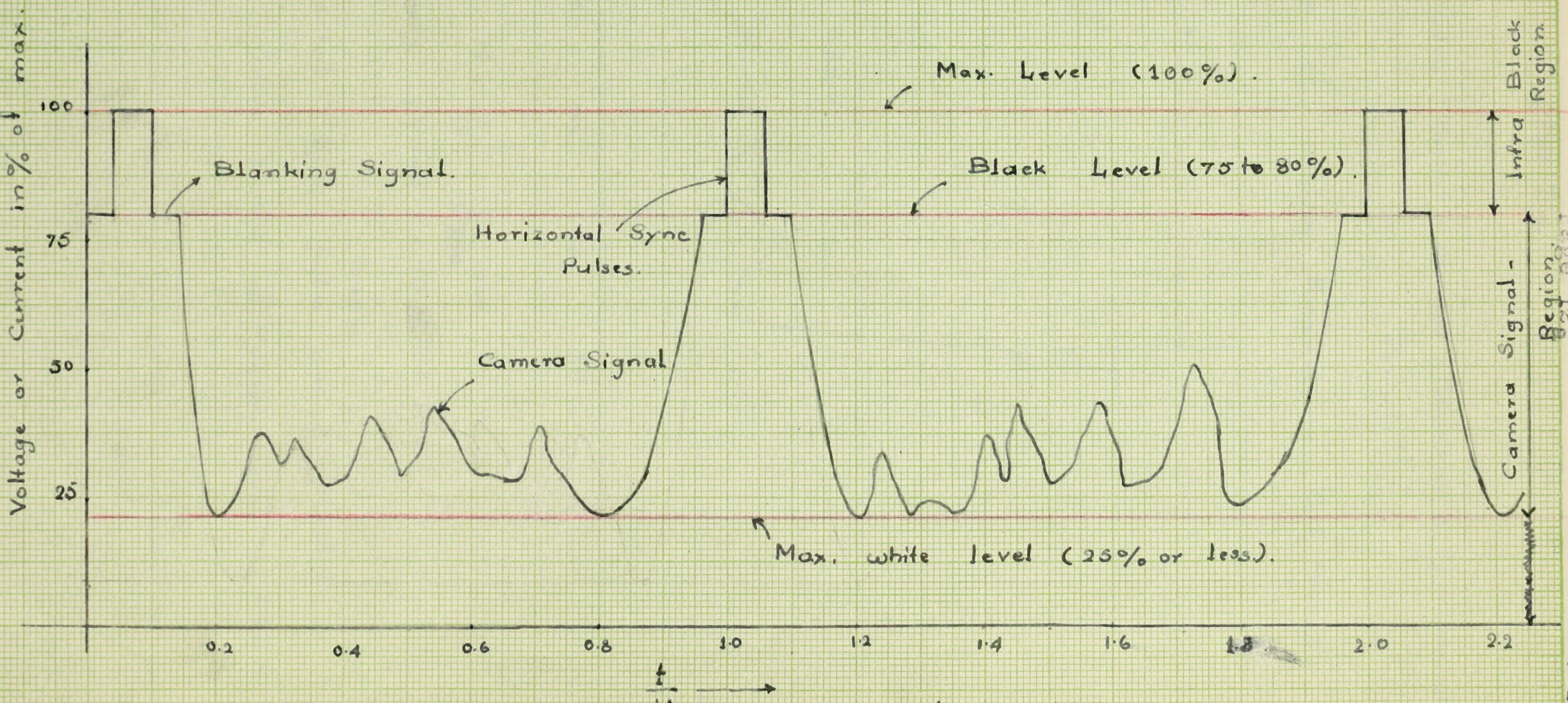
"Two lines and Blanking periods of R.M.A. Video Signal".

(Principles of Television Engineering – D.G. Fink.).

H = the line, scanning interval,

: time interval, between the beginnings of two successive lines.

$= \frac{1}{nf}$ where n = no. of times, a std. scanning pattern, traces & retraces itself.

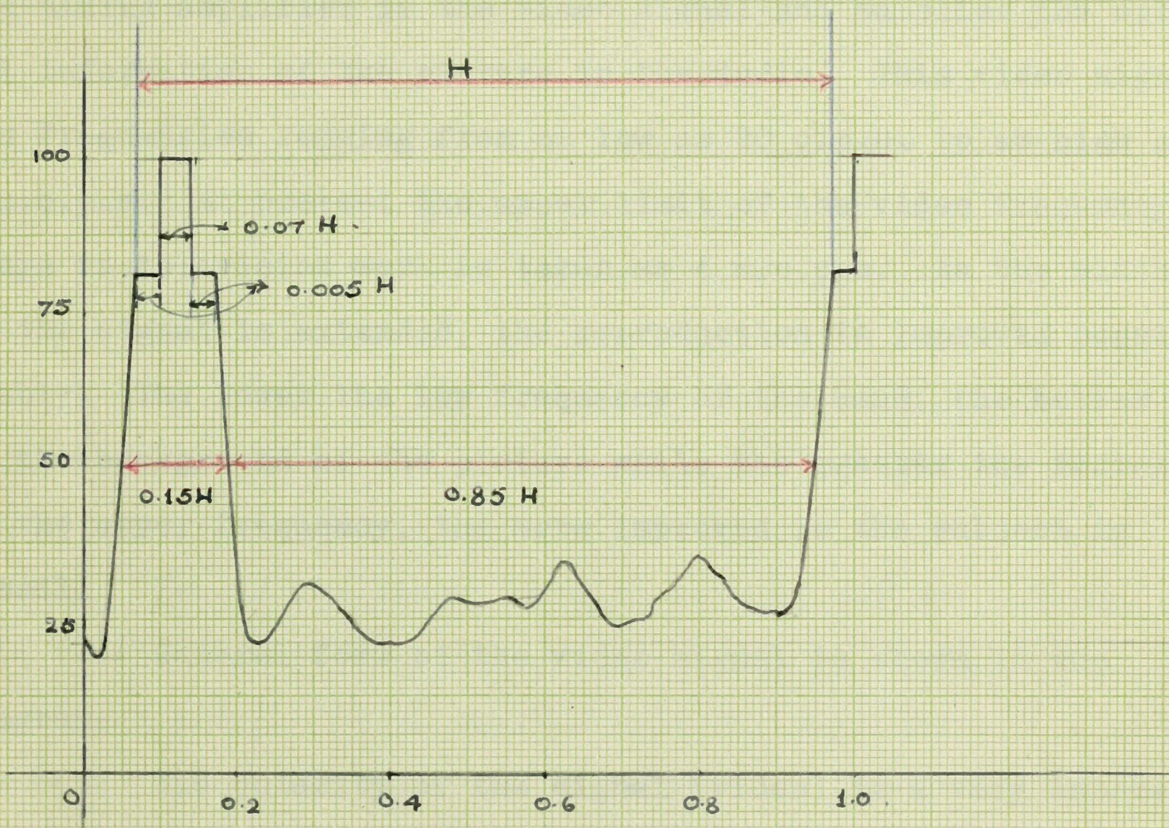


H = 1/15,750 th. second.

Diagram. 10.

" Std. Video Signal, showing Blancking & Synchronization Periods".

(Principles of Television Engineering - D.G. Fink.)



Std. $H = \frac{1}{nf} = \frac{1}{15,750}$ sec.

Blanking period $= 15\%$ of H

$= 0.15\,H$.

Horizontal Sync pulse period $= 0.08\,H$.

∴ The active period of reproduction $= 0.85\,H$.

Chapter III ... General Discussion of Video Signal

As seen in the previous discussion, the output of the mixing amplifier is the video signal and supplies the optical information of the picture in thestudio. This video signal has frequencies ranging from as low as 20 c.p.s. to as high as 4 m.c.p.s. At present the upper limit of the video frequency range in television work is taken as 4 m.c.p.s. As the width of the signal is extended, the reproduction is improved considerably. The lower the low frequency of the band, the better is the background of the picture while the greater the increase in the upper frequency, the more improved is the subject in detail.

General form of the video signal is shown in the diagram.

The polarity of the signal (video) is a very important factor as it determines the tones or colours of the reproduction. A receiver, designed for positive transmission of the picture (i.e. in which the signal amplitude increases with the brilliancy of the picture), if used to view negative polarity transmission produces a picture like a photographic negative. After long experimentation, the negative transmission, (ie, in which the signal amplitude decreases with increasing brilliancy of the picture) is preferred to positive transmission. The reason is that for negative transmission, if the signal level is raised, the signal enters the infra-black level further

(Ref. Nos. 1, 3, 4)

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and further, and black dots or lines appear in the picture. These black dots, as compared to white dots, that are present in the case of positive transmission are less conspicuous. (It is quite probable that interference may produce a drop in the signal level but the probability of the fall is very small as compared to that of the increase.)

The video signal diagram clearly shows that white tones or colors of the picture are produced by small amplitudes while successive higher amplitudes give deeper grey shades. When the amplitude reaches the black level the light is completely cut off. This black level is maintained constant during the transmission of video signal, its value being 75 to 80% of the maximum amplitude in the signal.

Beyond the black level is the infra-black region. This region is utilized in the application of synchronization and Blanking signals. It is obvious that the reproduction is not possible as long as the signal amplitude is in the Infra-black region. So the picture reproduction is carried on as long as the camera signal amplitudes are less than the black level.

From the diagram it is clear that the blanking pulses are applied during the interval that the scanning beam is going to the beginning of the next line after having completed the previous line. Generally, the amplitude of this blanking signal corresponds to black, sometimes blacker than black level. Thus no reproduction is carried out during the blanking interval.

At the beginning of the blanking period, the ampli-

tude of the signal is extended momentarily into the infra-black region by the application of horizontal sync. pulses. At the completion of the sync. pulses, the signal remains above the black level until the end of the blanking period. At the end of this period, the camera gains control over the signal and the scanning of the next line starts. (This process is repeated until 262 1/2 lines are scanned in which time the picture is scanned completely.)

Generally, the blanking period is maintained slightly longer than the time required to complete the retracing of the scanning beam as it helps in obtaining more reliable horizontal scanning. The width of the reproduction is slightly reduced because of longer than necessary blanking period but it is easily remedied by increasing the amplitude of the horizontal scanning current or voltage. (The second reason for the maintainance of longer than necessary blanking periods is the difficulty in mass production of scanning generators with retrace ratio 6:1).

During the retrace of the beam, by the sync. pulses, the vertical sync. pulses are applied to the camera signal. The period of these sync. pulses should be never less than 7%V & greater than 10%V. (Vert. blanking is 7-10%. There are 6 vert. sync pulses, total time = 3h)
where V = vertical field, scanning interval

$$= \frac{1}{f'} = \frac{1}{60} \text{ sec.}$$

Besides the two types of sync. pulses, equalisation pulses are applied to the blanking level. The restrictions of the vertical blanking period are such that it should end at least after 8 vertical sync. pulses are sent and the latest

Diagram 11 " N.T.S.C. Video signal, during the Vertical Blanking Period".

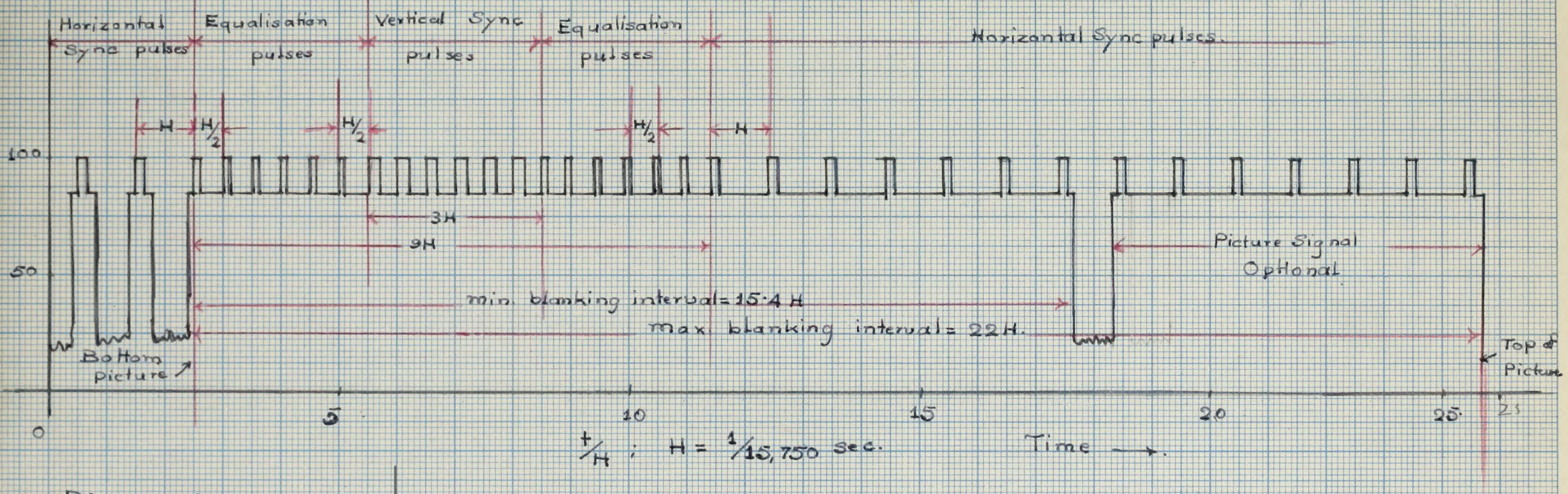
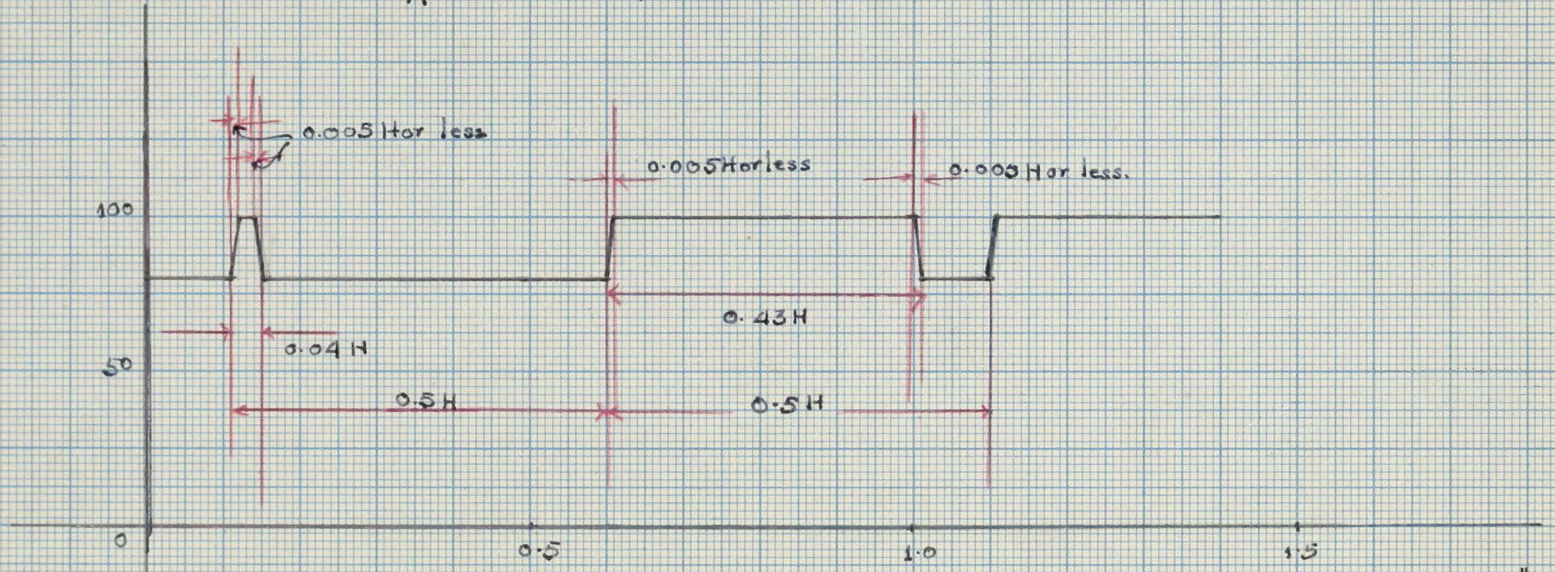


Diagram 12

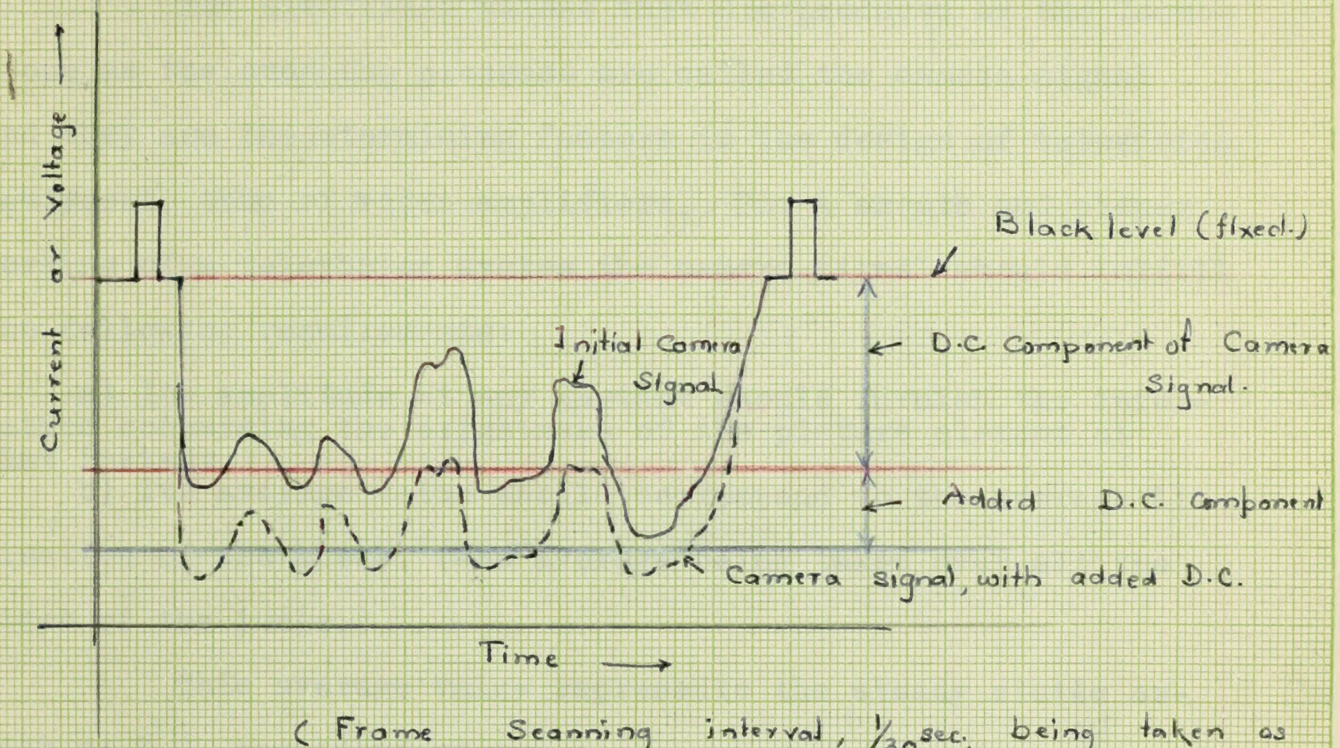


" Dimensions of Equalising & Serrated vertical pulses, in terms of H "
(R.M.A. Std. Video Signal).
(Principles of Television Engineering - Fink.).

after 13 horizontal sync. pulses are sent. The video signal with all the pulses and the periods mentioned above is shown in the diagrams.

Diagram 13.

"D.C. Component of Camera Signal."



(Frame Scanning interval, 1/30 sec, being taken as the interval, over which average is taken.)

(Principles of Television Engineering. D.G. Fink.)

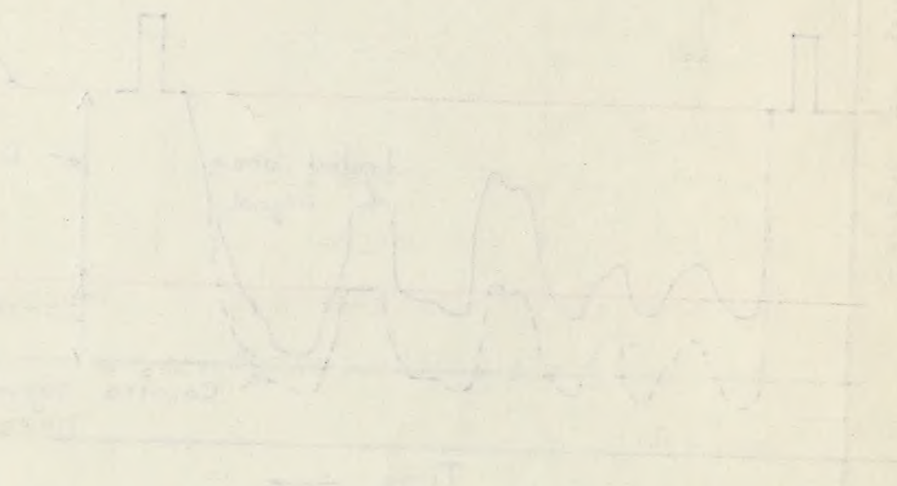


Figure [illegible]

[illegible]

Chapter IV ... Analysis of Camera Signal

The electrical pulses that are produced by the Iconoscope as the scanning proceeds are called the camera signal and they are the determining factors in the design of television equipment, thus of video amplifiers. For a smooth and proper working of a television system the camera signal should fulfill the following requirements:

a) Its amplitude at any instant should furnish the information concerning the brightness of the picture element at that instant.

b) Its average value should correspond to the average illumination of the scene. (The average being taken over all the lines of the image.)

This average value represents the steady state aspect or D.C. component of the camera signal as against the A.C. component. The A.C. component gives the information of the departure of the brightness of each element from the average value, while D.C. supplies the background information. As the black level is maintained fixed during the transmission, in the modulated carrier wave and also at the control grid of the picture tube, the D.C. can be made independent of A.C. regardless of waveform changes.

D.C. Component:

$$\text{D.C.} = \frac{\text{Average of the camera signal}}{\text{Frame Scanning Interval}}$$

From the diagram it is clear that the brightness of picture is a function of the change of the D.C. components.

For example, if the D.C. component is substracted from the camera signal keeping the A.C. component unchanged but shifted downwards, the brightness is improved. (negative transmission being considered.) The change in brightness ($\triangle$B) is given as: $\triangle$ B = amplitude of the subtracted D.C.

This brightness increment is generally accompanied by the reduction in the apparent brightness ~~contrast~~ of the image. Conversely for added D.C. component, the reduction in brightness is accompanied by the increase in the apparent brightness contrast of the image.

As seen in the discussion of Iconoscope, the output of the camera is devoid of D.C. component, so it requires to be fed externally with the D.C. component. There are three methods of insertion:

i) Addition of a voltage to the transmission circuit from a manually operated source of direct voltage.

ii) By the use of some types of image dissector tubes. Fainsworth Image Dissector automatically produces a D.C. component in the output.

iii)Use of a photo tube with Iconoscope to control the average level of its picture signal.

The insertion of a D.C. means the establishment of a level in the video signal in spite of the changes in the camera signal. So some level requires to be fixed as a reference. The blanking level which is fixed during transmission serves the purpose best. Sometimes the level of the tips of the sync. pulses can be considered as a reference level. These levels, blanking levels and sync pulse tips' level, are maintained fixed by passing a video signal through a rectifier and

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a load circuit which develops a voltage equal to the peak value of the signal. The rectification is generally carried before modulation in the modulating amplifier grid circuit thereby the constancy of the blanking level or sync pulse tip level is insured. The final rectification is carried out in the last video amplifier, thus a constant bias is maintained on the picture tube control circuit. The voltage developed in the load circuit associated with the rectifier above, serves as the D.C. portion of the signal. Once the level is fixed and established the variations of the average of the signal wave from this established level serve as the indication of the desired picture brightness and also of the changes required in the picture.(Most scenes don't utilize the full contrast range,discussed)

"A.C. Component of the Camera Signal":
It is due to the rapid changes in the voltage or current, corresponding to the brightness of the adjacent spots of a picture. If the reproduction is required to be undistorted, the A.C. of the camera signal should be transmitted undistorted. Besides this, the signal at the end of the transmitting circuit, should have zero level, the level giving the maximum brightness, and the black level at which the light is completely cut off.

The requirements are fulfilled by:

a) the adjustment of the D.C. component fed to the control grid of the tube

b) adjustment of the overall amplification of the signal; thereby the maximum and minimum values of A.C. are made to lie within the white and black levels.

(The waveform distortions, if any, should be studied and remedied at every point in the system.)

"The Video Frequency Range":

Let the camera signal be given by E(t), during the scanning of a line

$\therefore$ By Fourier analysis

$$E(t) = \frac{a_0}{2} + a_1 \sin 2\pi ft + a_2 \sin 2\pi(2ft) + \cdots + a_n \sin 2\pi(nft)$$
$$+ b_1 \cos 2\pi ft + b_2 \cos 2\pi(2ft) + \cdots + b_n \cos 2\pi(nft) \quad \ldots\ldots \quad A.$$

From A, D.C. = $\frac{a_0}{2}$ while the remaining terms indicate the A.C. components having frequencies equal to the multiples of frequency (f); f= fundamental frequency.

A on transformation:

$$E(t) = \frac{a_0}{2} + \sqrt{a_1^2+b_1^2} \sin\left(2\pi ft + \tan^{-1}\frac{b_1}{a_1}\right) + \sqrt{a_2^2+b_2^2} \sin\left[2\pi(2ft) + \tan^{-1}\frac{b_2}{a_2}\right] + \cdots$$
$$\cdots + \sqrt{a_n^2+b_n^2} \sin\left[2\pi(nft) + \tan^{-1}\frac{b_n}{a_n}\right] \quad \ldots \quad A'$$

$\therefore$ The phase of the A.C. component of frequency (f) w.r. to the origin at t=o is given by

$$\phi_1 = \tan^{-1}\frac{b_1}{a_1}$$

and amplitude = $\sqrt{a_1^2+b_1^2}$

Similarly for other components of A.C. of the camera signal. These phases and amplitudes can be evaluated by the mathematical formulae for Fourier coefficients but the method is too complicated to be used. Instead, some simplifying generalizations are made.

(From A' it is clear that for undistorted reproduction the relative amplitudes and phases of all frequencies components should be preserved.)

Generalisations:

i) As the lower frequency limit is based on the obvious fact that the L.F. that must be included in the video signal to indicate the light changes is the beginning of the interval for

(Reference : No. 4.)

Fourier analysis (30 c.p.s.)

ii) If this Fourier analysis is carried on smaller and smaller time intervals, a limit is reached. The reciprocal of this limit is the upper frequency limit of the video range and needs inclusion in the range.

So if the duration of a picture element is considered as the interval for Fourier analysis then the upper frequency limit is 3 m.c.p.s. (At present it is considered as 4 m.c.p.s.)

$\therefore$ The rate of picture elements = 6,000,000 per sec.

The upper frequency limit $= \frac{6,000,000}{2} = 3,000,000$ c.p.s.

$$\therefore f_{max} = 3 \text{ m.c.p.s.}$$

$\therefore$ The video frequency range is from 30 c.p.s. to 3 m.c.p.s. (4 m.c.p.s. at present)

The lower limit chosen is capable of handling the light variations occuring between successive frames, while the upper limit handles the light changes between successive picture elements. The intermediate degrees of detail are taken care of by intermediate frequencies. So the television system should be so designed that it transmits each and every component frequency with no amplitude distortion, their phases being proportional to the frequencies involved. (From this discussion it is clear that f_{max} is produced by the scanning of the finest detail in the picture.) (A Light & adjacent dark element combine to produce a cycle of the outputfrequency.)

"f_{max} in terms of m (the resolution ratio):

Let the total number (n) of lines of the s canning pattern consist of (n_a) active lines and let m be theratio of the horizontal and vertical resolution.

(Reference : No. 4)

$\therefore$ The number of picture elements (N) in such a pattern is given by :

$$N = \left(\frac{\omega}{h}\right) m k^2 n_a^2 \quad \text{picture elements}$$

where $\frac{\omega}{h}$ = aspect ratio

k = utilization factor

$\therefore$ The number of picture elements (n_h) in each scanned line is: $n_h = \left(\frac{\omega}{h}\right) m k n_a$

Let the frame frequency (f) be 30 c.p.s. and k_h and k_v be 7 and 12 respectively, then the rate (R) at which the picture elements n_h are sent out is given by:

$$R = \left(\frac{\omega}{h}\right) \cdot k m f n^2 \left(1+\frac{1}{k_h} \Big/ 1+\frac{1}{k_v}\right) \text{ per sec.}$$

$$= 1.054\, k m f n^2 \left(\frac{\omega}{h}\right) \text{ per sec.}$$

Consider two sq. waves being scanned at the rate R $\frac{\text{elements}}{\text{seconds}}$ and having the adjacent picture elements of different brightness $\therefore$ f_s = the frequency of the sq. wave

$= \frac{R}{2}$ c.p.s.

Now $\because f_{max} = f_s$ $\quad \therefore f_{max} = \left(\frac{\omega}{h}\right) \frac{k m f n^2}{2} \left(1+\frac{1}{k_h} \Big/ 1+\frac{1}{k_v}\right)$ c.p.s ... B.

Generally $\left(\frac{w}{h}\right)$ f and m are determined by the transmission standards while k is determined by the nature of the scanning pattern. The retrace ratios (k_h and k_v) are functions of the scanning equipment and its performance.

$\therefore$ The f_{max} is controlled by "m" alone; m depends on the size of the scanning spot.

So the max. frequency of a video band is a function of the resolution of the scanning agent. (In the case of attenuation of the signal, the max. frequency of the video signal is less than the f_{max} already obtained.)

(Reference: No. 3 and 4)

Some f_{max} with its determining factors are tabulated below:

No.	No. of scanning lines (n)	No. of $\frac{frames}{sec.}$ (f)	f_{max}, m=1 c.p.s.	f_{max}, m=1.33 c.p.s.
1	20	16	3,360	4,490
2	60	16	30,200	40,250
3	120	24	181,500	242,000
4	180	24	410,000	546,000
5	240	30	727,000	970,000
6	343(7x7x7)	30	1,860,000	2,440,000
7	441(7x7x3x3)	30	3,060,000	4,080,000
8	1029(7^3x3)	30	16,650,000	22,100,000

(Reference: Fink: Principles of Television Engineering.)

(1029 lines, 30 $\frac{frames}{sec.}$ is the possible case, available in the future. At present m=1.33 produces the max. video frequency with R.M.A. standard pattern of 4.08 m.c.p.s. and this is the limit to which the modern television sets respond perfectly.)

Effects of high f_{max}:

The increase in the magnitude of f_{max} in a video range has the following effects on the reproduction:

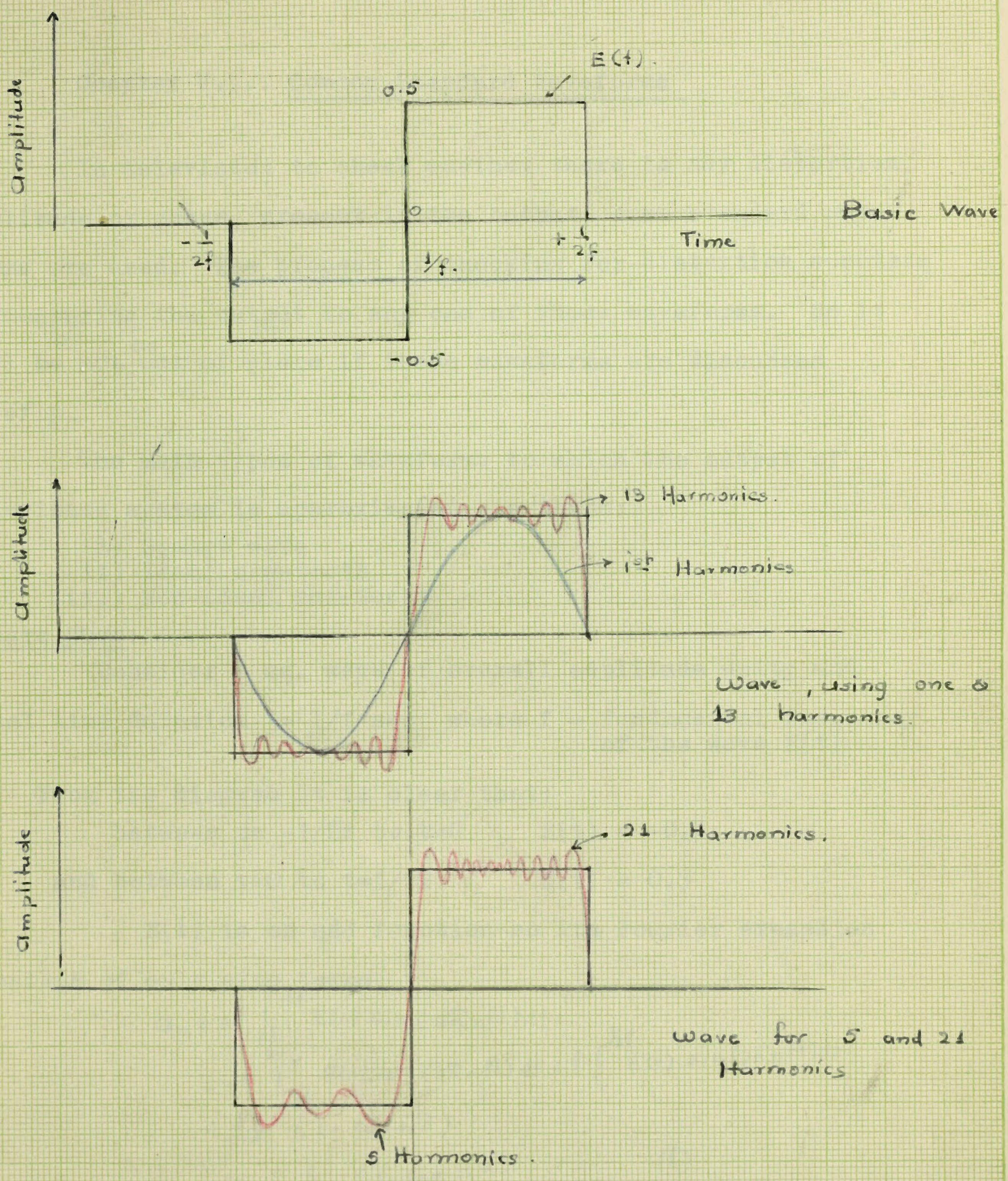
i) The details of reproduction are made finer, the extended edges are made finer and overall reproduction is improved in uniformity.

ii) The picture with non-uniformity (with extended regions in some portions and fine details in other portions) is better reproduced provided all the frequencies (f_{max} inclusive) are transmitted perfectly.

(Ref: Nos. 3, 4)

Diagram. 14.

"Sq. Wave and its Harmonics"



Chapter V.... Common Standard Waveforms

In television to check whether there is any distortion, amplitude or phase, present in the output, some standard waveforms are used. The process of checking for distortion consists in comparing the output to any one of these waveforms. So it will not be out of place if these waveforms are discussed briefly.

The main types of waveforms to which the output of a television system is approximated are three:

i) Square wave
ii) Ideal saw-tooth
iii) Non-ideal saw-tooth

Square Wave:

Consider a sq. wave of overall amplitude unity and total time duration $= 1/f$ sec where f = fundamental frequency of the wave $E(t)$

From the diagram it is clear that:

between $t = -1/2f$ to $t=0$ $\quad E(t) = -0.5$

and between $t=0$ to $t=1/2f$ $\quad E(t) = 0.5$

$\therefore$ $E(t)$ is an odd function so its Fourier expansion consists of only sine terms:

$$\therefore \quad a_n = 2f \int_{-\frac{1}{2f}}^{\frac{1}{2f}} E(t) \sin(2\pi n f t)\,dt.$$

$$= -f \int_{-\frac{1}{2f}}^{0} E(t).\sin(2\pi n f t)\,dt + f \int_{0}^{\frac{1}{2f}} E(t).\sin(2\pi n f t)\,dt.$$

$$= \frac{1}{n\pi}\,(1 - \cos n\pi)$$

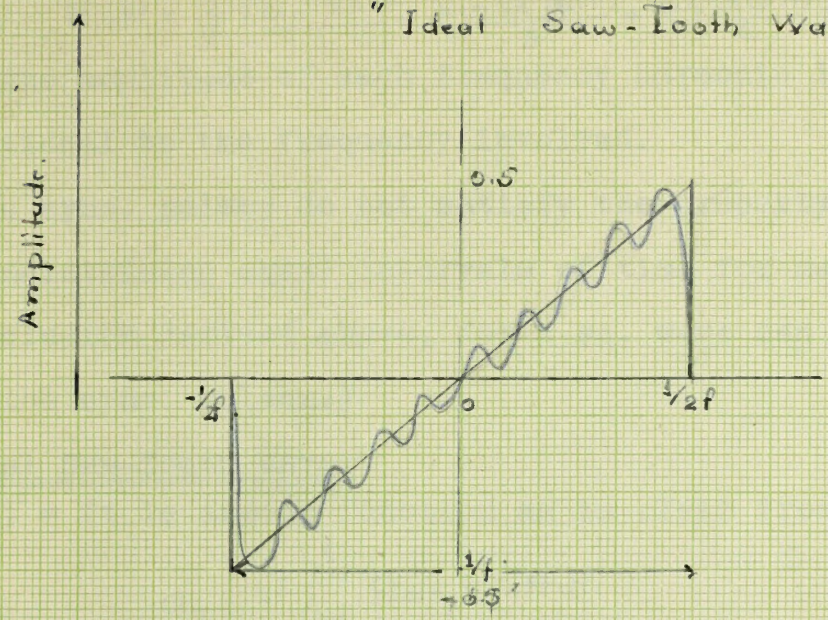
$$\therefore \quad a_n = \frac{1}{n\pi}\,(1 - \cos n\pi) \quad \ldots \quad (1)$$

$\therefore a_2, a_4$ ....together with a_0 are all zero.

(Reference : No. 3,4,6)

Diagram. 15

"Ideal Saw-Tooth Waveform - its Harmonics".

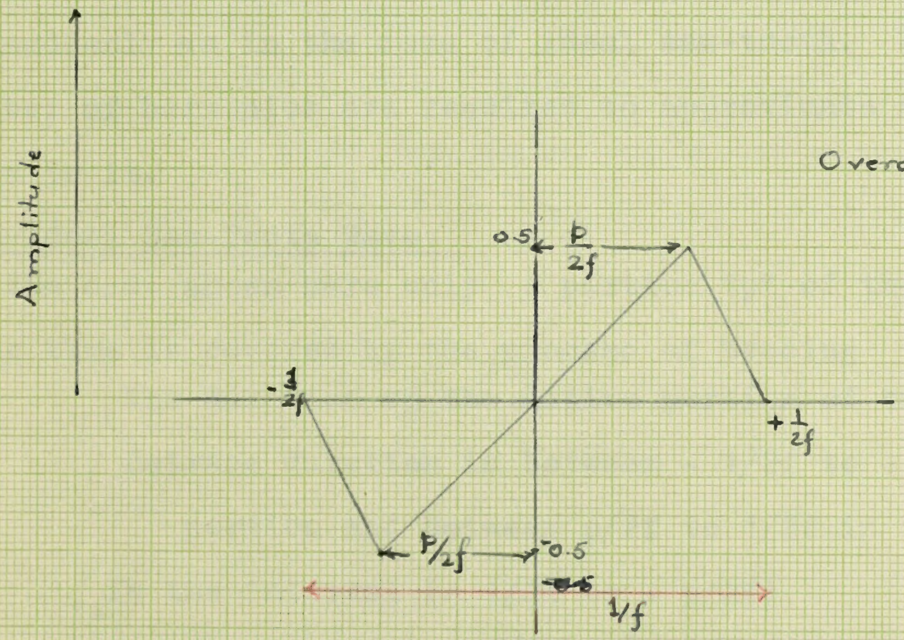


Overall amplitude = unity

$E(t) = ft$.

Diagram. 16.

"Non-Ideal Saw-Tooth Waveform".



Overall amplitude unity.

$$\therefore \quad E(t) = \frac{2}{\pi}\left[\frac{\sin 2\pi ft}{1} + \frac{\sin 2\pi(3ft)}{3} + \frac{\sin 2\pi(5ft)}{5} + \dots + \frac{\sin 2\pi(nft)}{n}\right] \dots (2)$$

So the amplitude of each frequency harmonic is inversely proportional to the frequency involved.

(The sync. pulses do not satisfy the property of the sq. wave of maintaining equal intervals of time for max. and min. The conclusion derived above, for a sq. wave can still be applied to the sync. pulses.)

Ideal Saw-Tooth Wave:

$E(t) = ft$ is an even function as is clear from the diagram.

$$\therefore a_n = 2f\int_{-\frac{1}{2f}}^{\frac{1}{2f}} ft \sin 2\pi nft\, dt.$$

$$= -\frac{1}{n\pi} \cos n\pi.$$

$$\therefore E(t) = f(t) = \frac{1}{\pi}\left(\frac{\sin 2\pi ft}{1} - \frac{\sin 2\pi(2ft)}{2} + \frac{\sin 2\pi(3ft)}{2} - \frac{\sin 2\pi(4ft)}{2} + \dots \dots - \cos n\pi \frac{\sin 2\pi nft}{2}\right) \dots \quad (3)$$

Generally, in practice, the retraces do not take place so suddenly as in the case of ideal saw-tooth. Thus a large number of harmonics are required to approximate a given waveform to it.

Non-Ideal Saw-Tooth Wave:

In the case shown here only a portion "p" of the total scanning time is covered by the process of tracing

$\therefore$ The duration of the active portion of the wave$=p/f$ sec.

$\therefore$ Retrace duration is between $-1/2f$ to $-p/2f$ in negative portion and between $p/2f$ to $1/2f$ in positive portion.

$\therefore$ In the interval $(-1/2f$ to $-p/2f)$

$$E(t) = -(f/1-p)\,(1/2f + t)$$

In $(-p/2f$ to $p/2f)$ $\quad E(t) = (f/p)t$

In $(p/2f$ to $1/2f)$ $\quad E(t) = \frac{f}{1-p}\left(\frac{1}{2f} - t\right)$

(Ref. No 6,4,3.)

$$\therefore \; a_n = 2f\left[\int_{-\frac{1}{2f}}^{-\frac{p}{2f}} -\frac{f}{1-p}\left(\frac{1}{2f}+t\right)\sin 2\pi nft\,dt + \int_{-\frac{p}{2f}}^{\frac{p}{2f}} \frac{f}{p}\, t\sin 2\pi nft\,dt + \int_{\frac{p}{2f}}^{\frac{1}{2f}} \frac{f}{1-p}\sin 2\pi nft\,dt\right]$$

$$\therefore \; a_n = \frac{1}{p-p^2}\;\frac{\sin \pi np}{n^2\pi^2} \quad . \; . \; . \; . \; . \quad (4)$$

$$\therefore \; E(t) = \frac{1}{\pi^2(p-p^2)}\left[\frac{\sin \pi p \sin 2\pi ft}{1} + \frac{\sin 2\pi p \cdot \sin 2\pi(2ft)}{4} + \dots + \frac{\sin n\pi p \sin 2\pi(nft)}{n^2}\right] \quad . \; . \; . \; . \; . \quad (5)$$

So in this case the amplitudes are decreasing with the square of the order of the harmonic.

These are some of the standard waveforms to which a television output can be approximated and checked for distortion. These are useful only when the output is periodic. Sometimes the picture signal is non-periodic. Such non-periodic pulse is called "the transient pulse" and the response of the television amplifier to this transient signal gives the general criterion of video response. This transient signal is called the Heaviside Unit pulse, also.

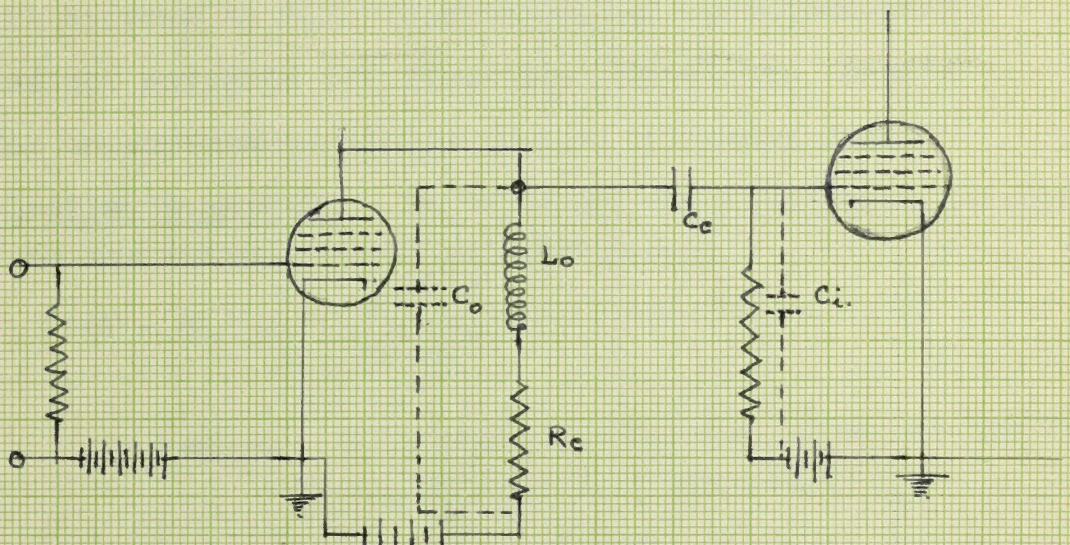
<u>Heaviside Unit pulse</u>:

It consists of a unity amplitude voltage pulse whose period is greater than the duration of transient (response). If this pulse is applied to a video amplifier, the response is perfect if the amplitude and phase responses are uniform from zero to infinity. But in practice the frequency responses being restricted, the output is distorted.

This transient analysis shows the extent of distortion due to use of specified range and brings out the specified

Ref. No. 4

Diagram 17.



Mc Lachlan's Method. (Transient Response.)

irregularities within that range. There are two methods available to determine the transient response of an amplifier.

1) Operational Calculus
   a) Lane..Uncompensated stages
   b) McLachlan..Shunt Compensated Stages

2) Fourier Series - Bedford and Fredenhall

(As will be seen in H.F. considerations, uncompensated stages are not suitable for video amplification. Lane's method for uncompensated stages is not discussed here.)

McLachlan's method: It is based on operational calculus. Let e(t) be the output of the circuit shown.

Then
$$e(t) = g_m R_c \left[1 - \frac{\epsilon^{-\pi f_r k t}}{k\sqrt{1-\frac{k^2}{4}}} \sin(Mt+\theta) \right] \quad \ldots \quad (6)$$

where f_r = resonant frequency of L_o and $C_t (= C_o + C_i)$

$k = \frac{R_c}{X_{ct}}$ at f_r ; $M = 2\pi f_r \sqrt{1-\frac{k^2}{4}}$

and
$$\theta = \tan^{-1} \frac{k\sqrt{1-k^2/4}}{\frac{k^2}{2}-1}.$$

(Applicable only to one stage and when $(C_o + C_i)$ are effective.)

If the phase and amplitude characteristics are known, Fourier integral gives:

$$e(t) = \frac{r_{d.c}}{2} + \frac{1}{\pi}\int_{-\infty}^{\infty} r_f \frac{\sin \omega(t - p_f)}{\omega}\, d\omega \quad \ldots \quad (7) \qquad \omega = 2\pi f.$$

where $r_{d.c}$ = d.c. response of the amplifier

r_f = the amplitude frequency response function

p_f = phase, frequency response function

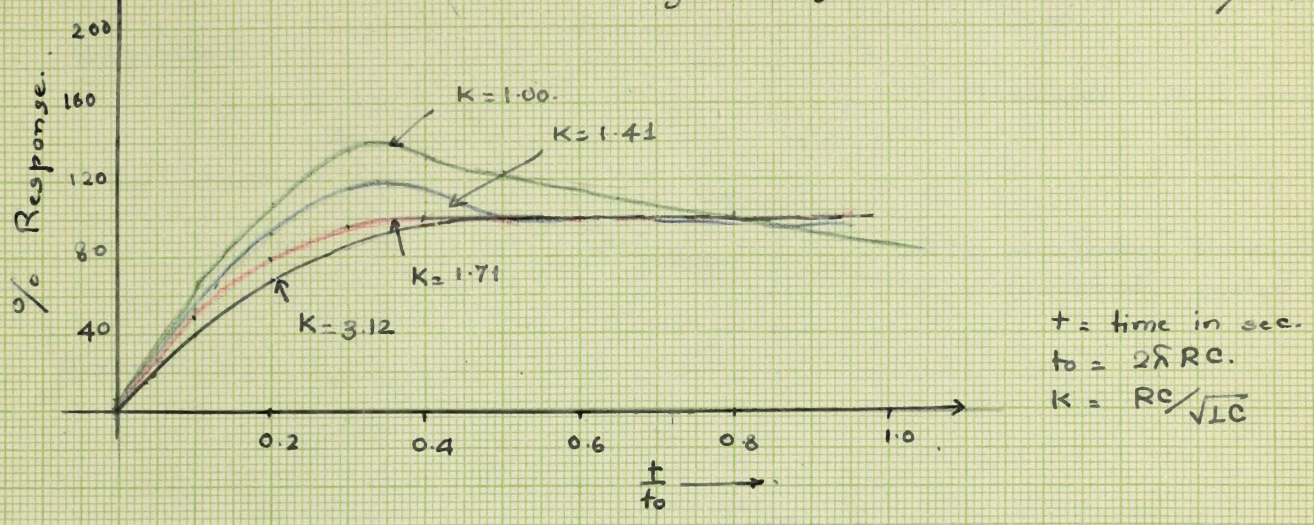
This equation (7) is generally solved graphically so the solution is tedious. This method though accurate is not popular to obtain the transient response.

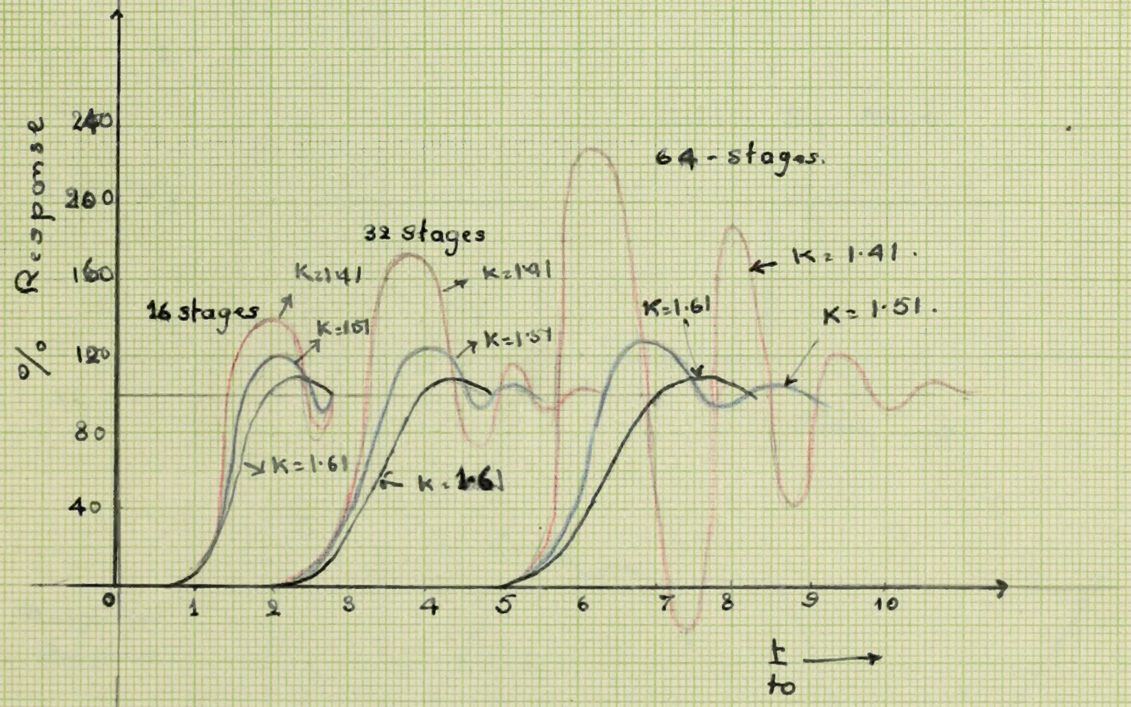
(Ref: Nos. 4, & 7)

Diagram. 18

Page 26a

a) "Transient Response for a Single Stage".
(Radio Engineering Handbook - Henney.).



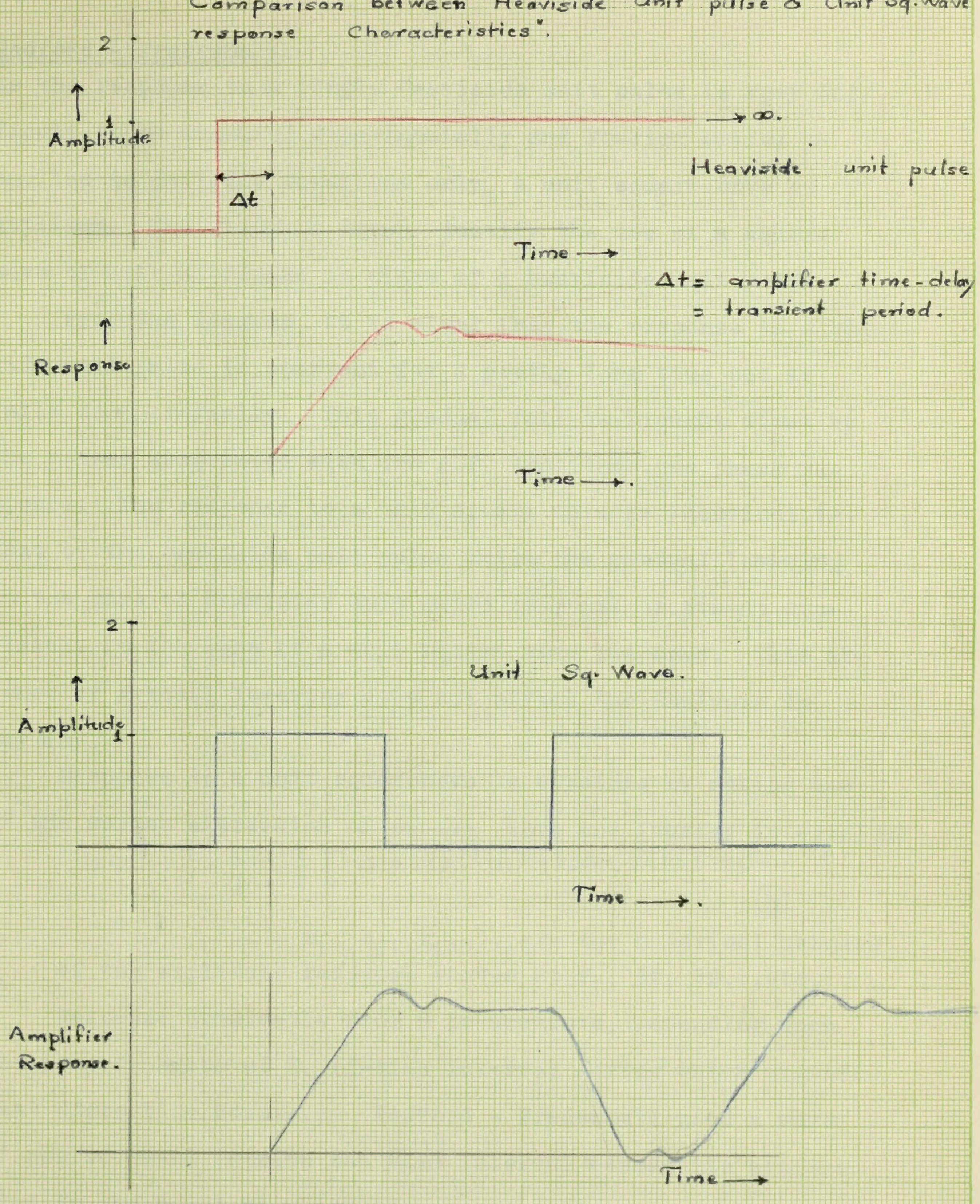


b). "Transient Response for Multi Stage Compensated Video Amplifiers" (Bedford - Fredenhall)

Case for K = 1.51 (equivalent to $K_R = 1$, $K_L = 0.41$) serves the best.

Diagram. 18 c.

"Comparison between Heaviside Unit pulse & Unit Sq. Wave response Characteristics".



(Bedford-Fredenhall.).

Bedford - Fredenhall:
As the response to a single Heaviside unit pulse is very difficult to be measured experimentally and Fourier series is applied to periodic functions only, a unit square wave is utilized. The diagrams drawn, justify the use of a square wave of unit amplitude in place of a Heaviside unit pulse.

From the diagram, it is clear that the response to a Heaviside unit pulse is constant for a pretty long time but it falls down gradually. This gradual fall is brought about by the causes associated with the L.F. Amplitude and phase response. The response to a unit square wave is identical to that of the Heaviside unit pulse while the gradual lowering in the case of Heaviside unit pulse response is absent completely in the case of a unit square wave response. This absence of gradual lowering does not affect the analysis in any way.

Response to a unit squarewave is obtained by making use of the series expression of square wave and Fourier integral in 7

$$\therefore\ e(t) = \frac{1}{2} + \lim_{f \to 0} \frac{2}{\pi}\left[r_1 \sin 2\pi f(t-p_1) + r_3 \sin 2\pi f(t-p_3) + \cdots \right] \qquad \cdots (8)$$

r_1, r_3, r_5.....are the numeridal heights of the amplitude response curves at f_1, 3f, 5f...etc.

Response obtainable from 8 is accurate, d-epending upon the proper choice of f. (f=time interval during which significant distortion occurs.) Bedford - Fredenhall used a wave of period equal totwice the time interval between its application to the point at which it becomes unity.

This analysis can be applied to multi-stage amplification.

(Ref: Nos. 1, 4, 7)

The results of such analysis are plotted.

From these curves it is clear that k=1.51 is the best characteristic for the purpose of television (video) work and the response becomes smoother and better as the number of stages in increased. In thecase of k=1.41 (ie. an amplifier with $k_1 = 0.50$), there are sudden and extreme increases in amplitude. These upsurges have the effect of producing a sudden change of colour in the reproduction such as a black dot following a change inthe white direction and vice-versa. While, the second amplifier with k=1.51 having only 10% overshootings, is more suitable for television work.

($k = RC/\sqrt{LC}$ = ratio of the load resistor to the impedance of shunt capacitanes C_t at the resonant frequency (f_r) of L and C_t)

This transient response analysis can be applied to any output of a television system.

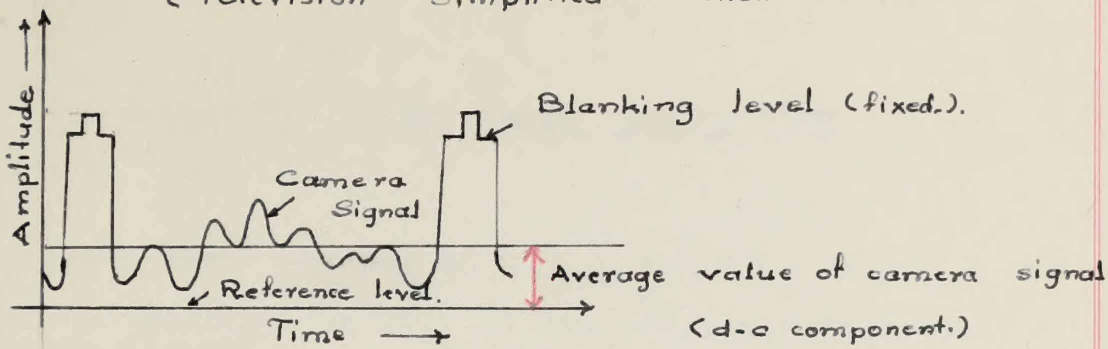
Usual design calls for $R_L = X_C$ at f_o where $f_o = 1.4 f_{max}$ and f_{max} = highest desired frequency having 1:1 response. This gives a circuit of $Q = 1$ which has unique properties of impedance and phase shift. $X_L = C_c$ at f_o.

L.F. Response:

Though it is possible to sacrifice some response at the H.F. end of 4 megacycles signal, it is necessary that the amplifier should have a uniform response to 30 cycles. So the characteristic must extend downwards to 10 cycles or even less, as the amplifiers do not cut off sharply at any on frequency.

Effect of Loss of response at Low Frequencies: -

(Television Simplified - Milton S. Kiver)



From the diagram it is clear that on either side of the line there are blanking and synchronizing pulses. These pulses have a fixed level while the camera signal between the pulses differ from one line to the next. These changing voltages are referred to as a.c. variations of the television signal. Besides these there is a D.C. component of the camera signal.

From the discussion of the D.C. component of the camera signal, it is clear that the average illumination of the scene may change with each frame or 30 times a second. In order to have the scene televised exactly, the average illumination should remain constant. This, in turn, is guaranteed if the transmit-ing and receiving circuits are capable of passing 30 c.p.s. without too great attenuation. Any poor response would result in incorrect values of the background illumination and would result in the left to right stretching or smearing of the large objects.

So the low frequency response should be perfect for the smooth working of video-amplification. The circuit (compensating) suggested and discussed in the chapter in Video-

Amplifiers L.F. Considerations, helps in controlling this L.F. response.

Chapter 6......Waveforms' Distortions

Many times the output of a television system is not identical to the input because of distortions. These distortions may be due to various reasons but the following are the main ones: i) distortions due to non-ideal amplitude and phase response characteristics.

ii) Distortions due to the presence of masking voltages (noise)

iii) Distortions due to purposely introduced disturbances to improve the quality of the reproduction.

Distortions due to non-ideal characteristics:

These distortions can be subdivided into two types, a) Symmetrical distortion....non-ideal amplitude characteristic, b) Anti-symmetrical distortion....phase shift of harmonics present with respect with one another.

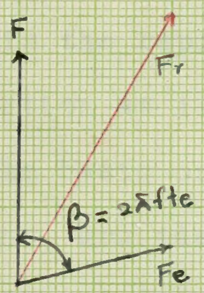
Consider a unit pulse, ie., a non-periodic waveform containing one pulse of unit area and with its amplitude large when compared to the duration of the pulse. This pulse consists of infinite number of harmonics of equal amplitudes (Fourier Analysis.) So for its undistorted transmission the harmonics should be transmitted undistorted which is not possible in practice.

The diagram shows the basic unit pulse and its reproduction after it passes through a circuit with a response

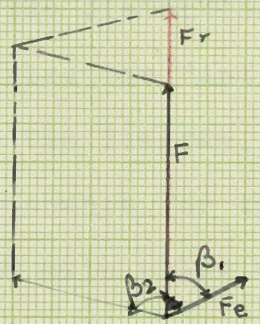
Diagram 19

"Vector Addition of Main & Echo Frequency Components".

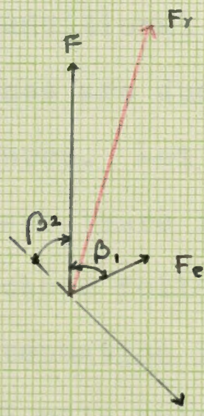
(Television - Zworykin Morton.)



Single Echo



Positive Pair of Echoes.



Negative Pair of Echoes.

F = Amplitude of the Main Pulse.
F_r = Amplitude of the Resultant.
F_e = Amplitude of the Echo.

$\beta = 2\pi f t_e$, $\beta_1 = 2\pi f t_e$; $\beta_2 = -2\pi f t_e$.
t_e = time before & after t_0 (the time, at which the impulse is applied) the echoes occur.

characteristic of the nature shown. The response characteristic is a function of frequency F(f).

The reproduction E(t) with no phase distortion is;

$$E(t) = 2\int_0^\infty F(f)\cos 2\pi ft\, df \quad . \; . \; . \; . \; . \; . \; . \; . \qquad (1)$$

This output wave is seen to be clearly symmetrical about the maximum amplitude of the input pulse.

In the presence of phase shift the distortion that wil be found in the reproduced waveform is called the "Anti-symmetrical" distortion as is clearly visible from the diagram. The echoes, the basis on which H.A. Wheeler accounts for the two distortions, are identical in shape to the main pulse but are highly attenuated. Their presence is accounted for by the distorted nature of the phase characteristics.

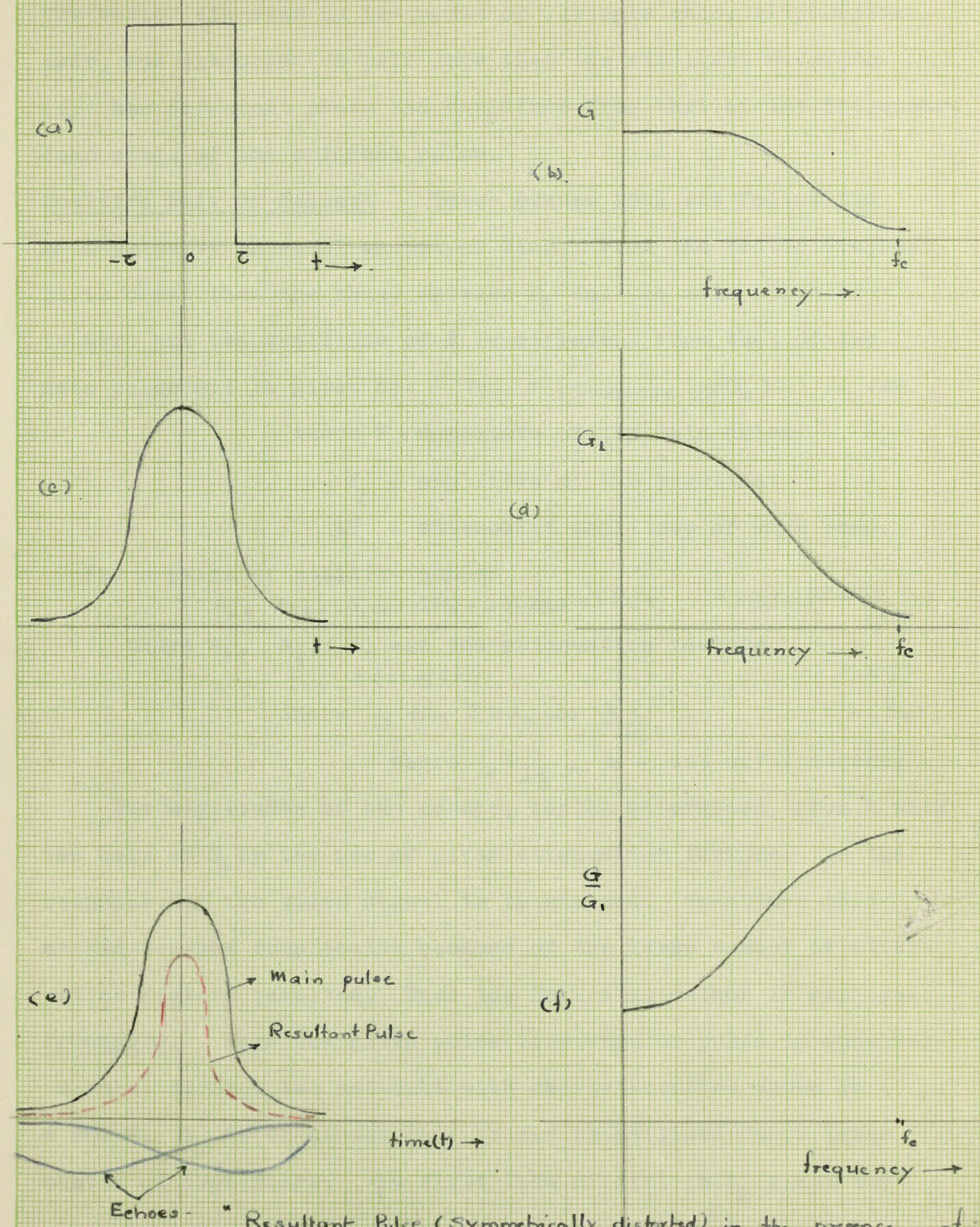
The Principle of Paired Echoes - H.A. Wheeler

Wheeler showed that the effect of small phase distortioncan be represented by the addition of two additional signals to the unit pulse. These additional signals have the form of the unit pulse. These echoes are due to the reflections that come from unmatched impedances. Let the input pulse reach the output in time t_o and appear there in its reproduced form accompanied by the pair of echoes following or preceding it by time t_e. The factor of attenuation is "a".

As the echoes and main pulse are identical in shape the echo frequency amplitudes are attenuated by a factor "a"; the phase (β) between the main pulse frequency and the corresponding echo frequency is given by $\beta = 2\pi f t_e$ . . . . . (2).

Ref. No. 1,7,4

Diagram 20



"Resultant Pulse (Symmetrically distorted) in the presence of Amplitude Distortion, with the help of +ve Paired Echoes".
(Television - Zworykin, Morton.)

The vector diagrams in the cases of i)single echo, ii)positive pair, and iii)negative pair show that the resultant waveform (f_r) has different phase and amplitude from that of the frequency components of the original pulse.

Positive Pair of Echoes: These echoes lead and follow the main pulse by an equal amount of time. From the vector diagram it is clear that the phase between F_r and the main pulse (F) is zero but the amplitude of F_r is different from that of the main pulse and is given by: $F_r = F\,(1+2a\cos 2\pi f t_e)$ . . . . (3)

where F = amplitude of the main pulse

F_r = amplitude of the resultant

aF = attenuated amplitude of each echo.

∴ For n pairs of positive echoes

$$F_r = F(1+2a_1\cos 2\pi f t_e + 2a_2\cos 4\pi f t_e + \cdots + 2a_n\cos 2\pi n f t_e) \quad \ldots (4)$$

where a_1, a_2,... a_n are the attenuation factors

$$F_r = F(1+g(f)) \quad \ldots \ldots (5)$$

where $$g(f) = \Sigma\, 2a_K \cos \frac{k\pi f}{2f_c} \quad \ldots \ldots (5a)$$

where $t_c = \frac{1}{4f_c}$; f_c = cut-off frequency

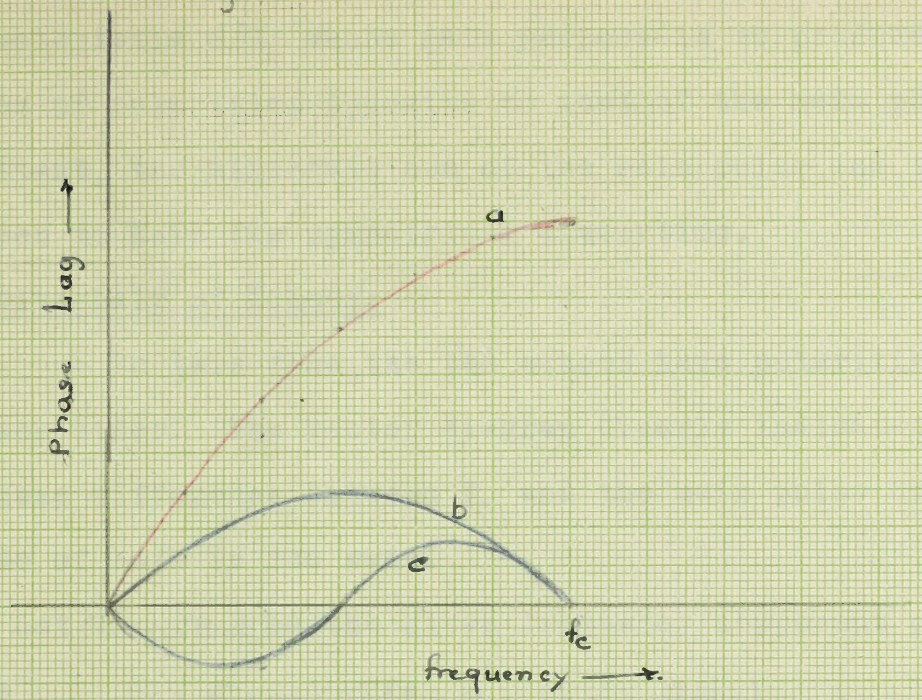
The magnitudes of the echoes, can be determined, from 5 with the help of 5_a by the use of given attenuation factors. So the response for the video signal is determined. Sometimes this method becomes complicated because of the large number of attenuation factors involved. Thus the following method is employed:

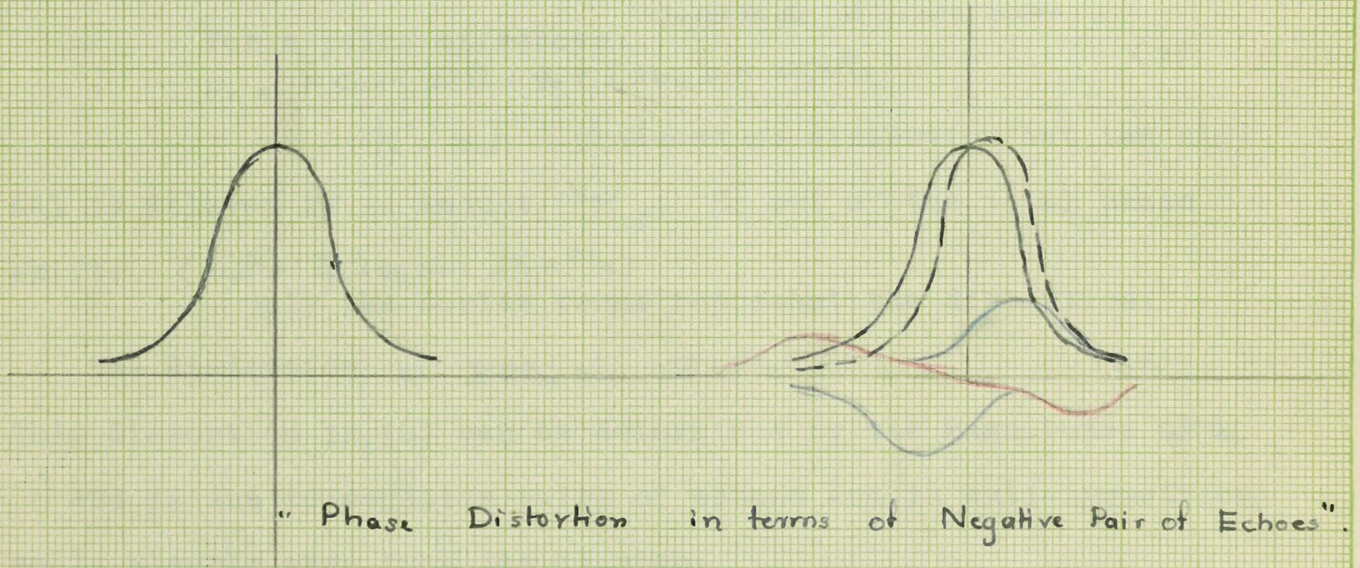
Procedure: Pass the given pulse (rectangular pulse is considered here) through two networks with characteristics shown in d and f. G_1 is so chosen that it can be utilised for a large number of amplifiers. The first term of g(f) in 5_a gives the

(Ref. Nos 1, 47)

Page 31a

Diagram 21.





" Phase Distortion in terms of Negative Pair of Echoes".

Phase characteristic (a) can be subdivided into two components "b" and "c", corresponding to terms.

$2b_1 \sin(2\pi f/2f_c)$ and $2b_2 \sin(2\pi f/2f_c)$ of

$\Sigma\, 2b_k \sin(2\pi k f/f_c)$.

(Television - Zworykin, G.A. Morton.)

characteristic G/G_1 whose main purpose is to produce a pair of echoes of polarities opposite to that of the main pulse. The resultant, the algebraic sum of the main pulse and the echoes is seen to have the symmetrical distortion.

Negative Pair of Echoes:

In this case the two echoes have polarities opposite to each other. The vector diagram clearly indicates that there is phase difference between E_r and the main pulse but the amplitude of both is the same.

Let $F\cos(2\pi ft+\phi_o)$ be the given frequency component of the main pulse $\therefore F_r = F\cos(2\pi ft + \phi_o + 2b\sin 2\pi fte)$ . . . . . . (6)

$$\phi_o = b_o f \ ; \quad f = \text{input frequency}$$

and b = attenuation factor = $\dfrac{\text{Amplitude of the echo}}{\text{amplitude of main pulse}} < 1$

$\therefore$ For n pairs of echoes:

$$F_r = F\cos(2\pi ft + \phi_o + \Sigma 2b_K \sin 2\pi Kfte) \quad \text{. . . . (7)}$$

$\phi_o = b_o f$ produces no distortion but the signal is delayed by an amount $b_o/2\pi$. So out of the total phase shift: $(b_o f + \Sigma 2b_K \sin 2\pi Kfte)$

only the series terms represent the distortion.

The distortion $= \Sigma 2b_K \sin 2\pi kfte$ . . . . (8)

This distortion in (8) can be determined by the magnitudes of b_K and is due to negative pairs of echoes and is anti-symmetrical as is clearly seen from the diagram.

Distortions due to Noise:

Generally the noise in a television appliance is due to many reasons but the most important of them are

a) Thermal Agitation in Resistances

b) The Emission Noises in Vacuum Tubes.

(Ref: Nos. 1, 4)

The emission noises or tube noises as they are popularly known are classified into: i) Flicker Effect, ii) Shot Effect, iii) The Space charge limited noise.

Besides these there are many other sources of noice. The thermal and shot effect noises arise in the video signal sources and the transmission equipment while the others arise in the carrier transmission of the signal.

a) Thermal Agitation Noise:

Johnson and Nyquist have shown that the e.m.f. generated across a resistor is due to the conduction electrons that are in thermal equilibrium with the atoms independent of the current flowing through and the material of which it is made. The thermal agitation in the resistors is due to the fluctuations of these conduction electrons; and the e.m.f. so generated is $e_{r.m.s.} = 7.4 \times 10^{-12} \sqrt{TZ\,(f_1 - f_2)}$ r.m.s. volts ..(9)

$e_{r.m.s.}$ = thermal voltage, (r.m.s. value)

T = absolute temperature of the conductor

Z = impedance

f_1 & f_2 = the lower and upper frequency limits. These thermal voltages are of the order of 2 to 100 micro-volts, corresponding to Z being of the order of 100 to 100,000 Ω.

b)Tube Noises:

i) Flicker Effect: Sometimes changes in the structure and composition of the cathode surface cause changes in the cathode surface emission. This change in the emission from the cathode surface is known as the Flicker Effect. The noise due to Flicker Effect is negligible over 1,000 cycles, and becomes

(Ref: Nos. 1, 3, 4, 7)

The relative merits of the [illegible] types are shown

graphically [illegible]: 1) [illegible], 2) [illegible] effect, and

the [illegible].

Besides these there are many other sources of noise.

The thermal agitation of [illegible] in the [illegible] and

sources and the transmission equipment [illegible]

in the earlier treatment of the signal.

a) Thermal agitation noise:

Johnson and Nyquist have shown

that the e.m.f. appearing across a resistor is due to the con-

ductive electrons [illegible] in thermal equilibrium with the atoms

independent of [illegible] the material of

which it is made. The thermal agitation in the conductors is

due to the [illegible] of [illegible] electrons; so the

e.m.f. generated is [illegible] $4kTR$ [illegible]

[illegible] voltage, (r.m.s. value)

[illegible] conductor

[illegible]

[illegible] These

thermal voltages are of the order of [illegible] micro-volts, cor-

responding to a [illegible] of the order of 100 to 100,000 [illegible].

b) Tube noises:

1) Flicker effect: [illegible] changes in the [illegible]

[illegible] of the [illegible] changes in the [illegible]

surface [illegible]. This change in the [illegible] surface

is known as the flicker effect. [illegible] due to

flicker effect is negligible over 1,000 cycles, and [illegible]

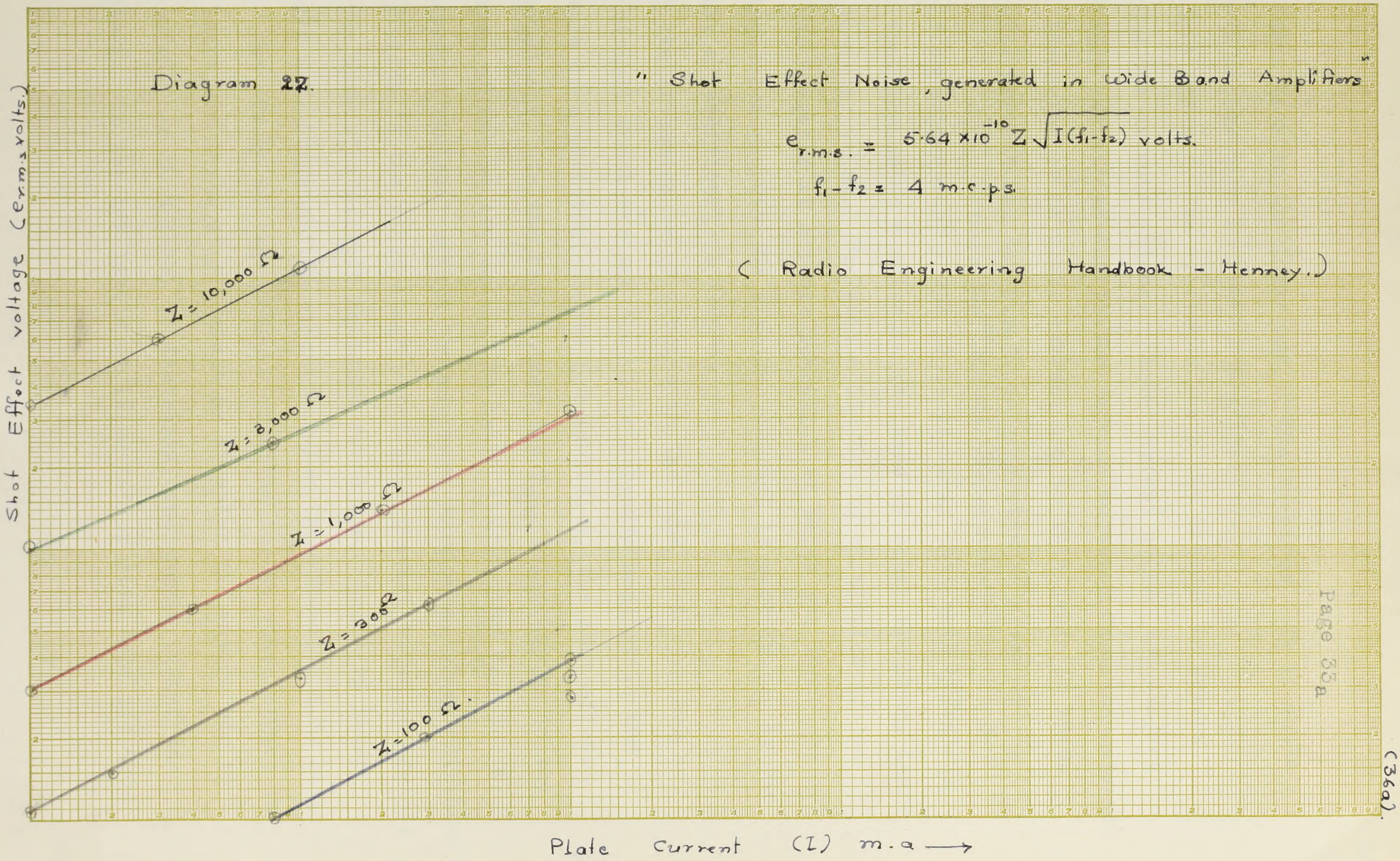

" Shot Effect Noise, generated in Wide Band Amplifiers"
$e_{r.m.s.} = 5{\cdot}64 \times 10^{-10} Z \sqrt{I(f_1 - f_2)}$ volts.
$f_1 - f_2 = 4$ m.c.p.s.
(Radio Engineering Handbook - Henney.)
Z = 10,000 Ω
Z = 3,000 Ω
Z = 1,000 Ω
Z = 300 Ω
Z = 100 Ω.
Shot Effect voltage (e r.m.s volts.)
Plate Current (I) m.a →

Diagram 27.

prominent towards the lower end of the spectrum. It is not a serious proposition in video amplification.

ii) Shot Effect: The electrons leave the cathode in groups forming the current pulses. These current pulses are subject to random variations due to the varying emission from the cathode. This irregularity in plate current due to this cause is known as "Shot Effect" and the e.m.f. so generated is given as:

$$e_{r.m.s} = 5.64 \times 10^{-10} Z \sqrt{I(f_1 - f_2)}\ r.m.s.\ \text{volts.} \quad --- \quad (10)$$

From expressions 9 and 10 it is clear that shot effect is more troublesome as a noise in the case of equal frequency range and resistor value. The shot noise can be eliminated if the tube is operated at a plate potential at which the space charge is developed whereby the electron current is made smooth by the supply of additional electrons.

The predominence of a noise in the tube is determined by the circuit constants and the plate currents employed. For example in a practical camera pre-amplifier, the shot effect is prominent. In the first stage the $f_{max} \doteq 1$ m.c.p.s. so the thermal effect is low and in the later stages, the f_{max} is increased so the shot effect becomes more prominent. The restricted band width in the first stage gives less thermal noise as against in the case of a circuit designed for 5 m.c. While in later stages H.F. Compensation circuits raise the effective H.F. limit.

The effect of the presence of noise in the video signal is to limit the level of illumination at which the camera can be operated. As this level is decreased, the camera signal decreases. So the low levels of illumination give hazy pictures

that are far from perfect.

$$\text{If } \frac{\text{Signal}}{\text{Noise}} = \frac{\text{Peak Camera Signal Voltage}}{\text{Peak noise (voltage)}} = 20$$

the reproduction is considered as good enough for entertainment purposes. If this ratio is made equal to 40 then the noise is completely eliminated.

In storage type tubes, the emission current is so small that the shot effect is negligible. But in the case of non-storage type tubes, the shot effect becomes a serious matter so electron multiplier structures are used to raise the signal to noise ratio. Electron multiplier structures give the highest possible Signal:Noise ratio by increasing the number of electrons flowing. From the expression 10 it is clear that as the frequency range is increased the shot effect noise is increased. Also it increases as the number of picture elements is increased. So the frequency range should never be longer than is actually necessary to convey the full information of the picture.

c) Purposely Introduced Noises: Sometimes some types of waveforms, blanking signal and the sync. pulses, are applied to the camera signal to improve the quality of reproduction. These signals also compensate for the limitations of the camera tubes and image reproducing tubes.

The expressions for the thermal & Shot effect noise volages are:

$$e_{r.m.s.} = 7.4\times10^{-12}\sqrt{TZ(f_1-f_2)} \text{ r.m.s. volts.}$$

$$e_{r.m.s.} = 5.64\times10^{-10} Z\sqrt{I(f_1-f_2)} \text{ r.m.s. volts.}$$

respectively.

From these expressions it is clear that the thermal noise

that are far from perfect.

If $\frac{\text{Signal}}{\text{Noise}} = \frac{\text{Peak}}{\text{Peak}} \; \frac{\text{Camera}}{\text{noise}} \; \frac{\text{Signal Voltage}}{\text{(voltage)}} = 20$

the reproduction is considered as good enough for entertainment purposes. If this ratio is made equal to 40 then the noise is completely eliminated.

In storage type tubes, the emission current is so small that the shot effect is negligible. But in the case of non-storage type tubes, the shot effect becomes a serious matter so electron multiplier structures are used to raise the signal to noise ratio. Electron multiplier structures give the highest possible Signal:Noise ratio by increasing the number of electrons flowing. From the expression 10 it is clear that as the frequency range is increased the shot effect noise is increased. Also it increases as the number of picture elements is increased. So the frequency range should never be longer than is actually necessary to convey the full information of the picture.

c) Purposely Introduced Noises: Sometimes some types of wave-forms, blanking signal and the sync. pulses, are applied to the camera signal to improve the quality of reproduction. These signals also compensate for the limitations of the camera tubes and image reproducing tubes.

The expressions for the thermal & Shot effect noise voltages are:

$$e_{r.m.s.} = 7.4 \times 10^{-12} \sqrt{T(f_1 - f_2)} \text{ r.m.s. volts.}$$

$$e_{r.m.s.} = 5.66 \times 10^{-10} \sqrt{I(f_1 - f_2)} \text{ r.m.s. volts.}$$

respectively.

From these expressions it is clear that the thermal noise

voltage is proportional to the sq. root of the frequency range of the band used & the sq. rt. of the coupling impedance.(The frequency range is generally determined by the image detail and the picture tube scanning system.)While in the case of the shot effect the noise voltage is proportional to the sq.rt. ofthe frequency range of the band,but is proportional to the coupling impedance, itself.)

From the discussion of the tube noises it is evident that as the coupling impedance in the grid of the amplifier stage,is increased,the signal increases accordingly.(assuming a constant current source).But as seen above ,the noise voltage increases as the sq.rt. of the coupling impedance.

∴ The Signal to noise ratio is increased .But in practice too large coupling impedances are avoided because of the following reasons:

1) The gas current that may be present in the amplifier tube ,might lead to the erractic variations of the grid bias of the tube,

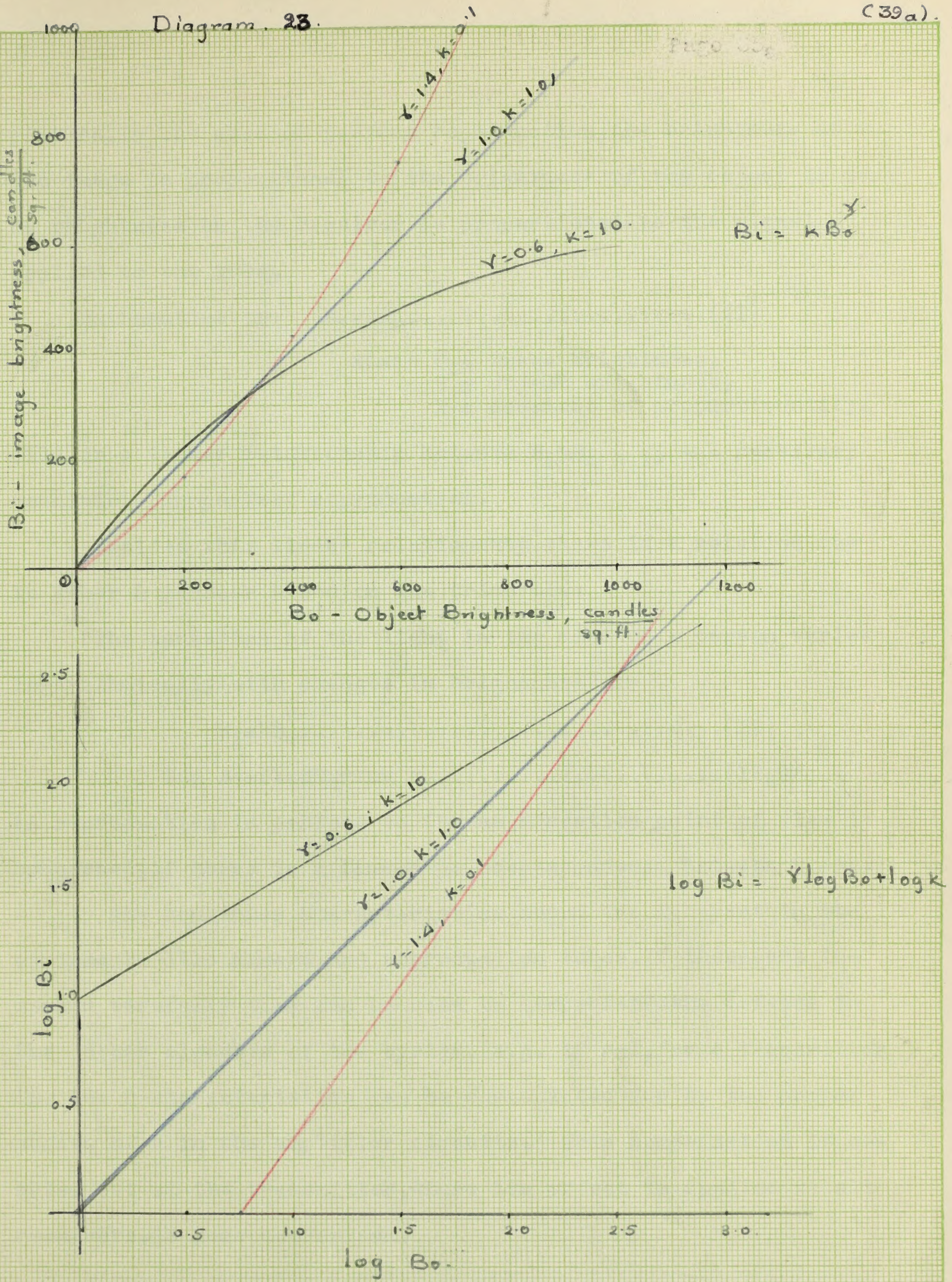
& 2) The camera tube is not a truly constant current generator.

Coupling impedances of the order of 100,000Ω may be used. Such high impedances lower the relative response at the high frequencies;but this loss can be compensated for , in a latter stage where noise is not a troublesome factor.

Brightness Relations for Perfect Reproduction:

From the discussion so far it is clear that the amplitude of the picture signal is proportional to the illumination of the

Diagram. 23.



" Brightness Transfer Characteristics of a Television System".
(Principles of Television Engineering . Fink.).

picture. In the case of perfect reproduction, the brightness of the image is proportional to the brightness of the object if the brightness on the receiver is proportional to the signal applied to the tube.

Mathematically: $B_i = kB_o$ ....(11)

where B_i = image brightness,
B_o = object brightness,
k = constant of proportionality.

(11) is a linear relationship between B_i & B_o & is the necessary condition for perfect reproduction.

Besides this linear relationship there is a relation due to Weber & Fechner based on the principle:

"The sensation of the light in the mind of a person varies logarithmically with changes in brightness"; or

$$B_i = kB_o^r \quad \text{..............................(12)}$$

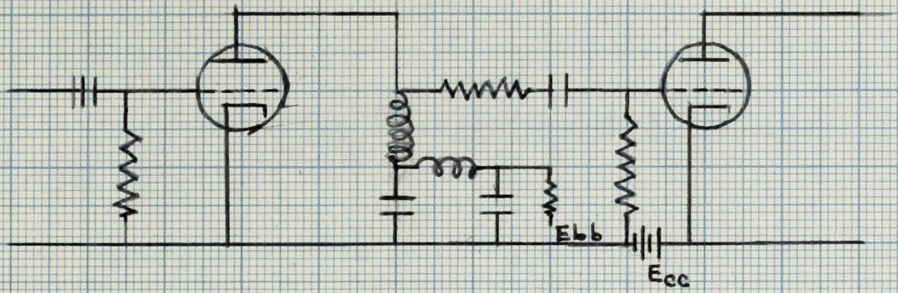
$$\log B_i = r\log B_o + \log k \quad \text{.....................(12a)}$$

(A reproduction is perfect as far as sensation point of view is concerned, if there is a linear correspondence between B_o & B_i.)

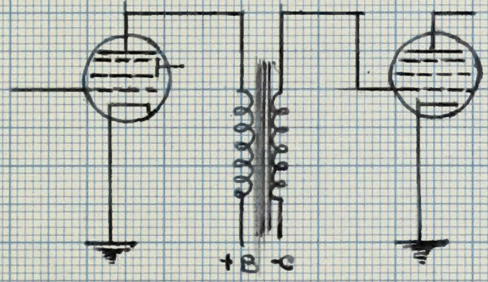
The nonlinear characteristics shown are inherent in the equipments like camera and reproduction tubes. If these are inserted carefully they can be used to compensate the defects in the other elements of the system. (e.g. if $r = 1$, for a transmitter the low r-characteristics can be compensated for by the proper choise of r in the amplifier circuits.) This compensation if carried out at the transmitter, where its effect is applied to all receivers, is more economical.

Ref: Nos. 3 & 4

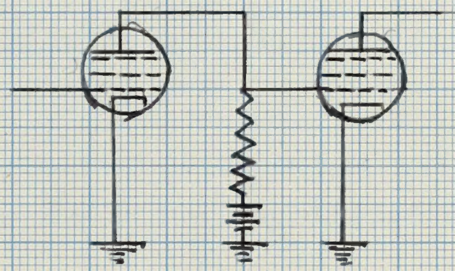
Diagram 24



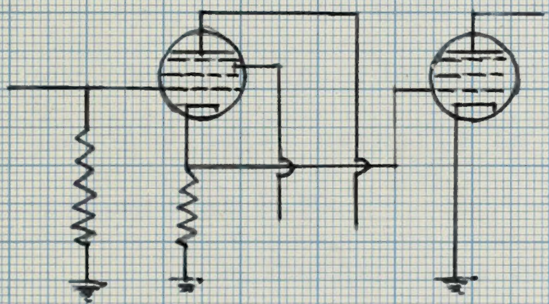
a) Inductance (Impedance) Coupled.



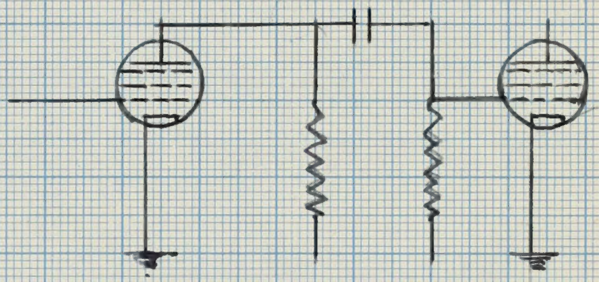
b) Transformer Coupled



c) Direct Coupled.



d) Cathode Coupled



e) Resistance Coupled.

"Different Couplings".

Chapter 7...Video Amplifiers,H.F.Considerations.

There are five main types of coupling for amplifiers named after the type of coupling.(the type of elements used for coupling.) There are many other combinations of the same elements but those that are drawn here are the fundamental ones:

i)Inductance coupled
ii)Transformer coupled
iii)Direct coupled
iv)Cathode coupled
v)Resistance coupled

First two types are unsuitable for video amplification because of:

a)The wide range (30c.p.s.-4m.c.p.s.)does not allow the use of known types of coupling chokes.

b)In the case of air core chokes,large number of turns are required in order to obtain sufficient impedance at L.F.so the ditributed capacity is high atH.F.For iron core there is no response at H.F.

c)Though there are some alloys(magnetic core)giving satisfactory results,they are undesirable because of the shifts and variations of impedance over the video range in use.

In the third case of coupling the plate of the first tube is at the D.C.potential of the grid of the second tube,Thi-s coupling theoretically can be seen to be the best suited one for the video amplification.The plate potential of the first tube can be adjusted to give the most satisfactory results--

(phase and amplitude characteristics) but the adjustment is so critical that it is not usable in practice.

The Cathode coupled amplifier has a gain of unity (and is constant) so it is not suitable for an amplifier but it is suitable for impedance matching. This coupling has a place in television set to couple a low impedance load (like a cable) to a voltage amplifier.

The last but the most suitable is the Resistance-coupled. It is used in the video amplification and is found to give the most satisfactory results by adjusting it properly for various corrections as will be seen as the discussion proceeds.

From the discussion of the video signal it is clear that for perfect reproduction the video amplifiers must be so designed as to have constant gain and zero or uniform time delay over the entire video range. (The R.M.A. standards are 525 lines interlaced scanning with a field-frequency of 60 c.p.s. and frame-frequency of 30 c.p.s.) So the amplifier must be capable of passing all the frequencies from 60 c.p.s. to 4 m.c.p.s. with constant gain and phase shift.

[Total time delay (ΔT) at any frequency $= \dfrac{\text{Total phase delay}}{\text{Angular frequency}}$

Fundamental frequency in video signal = 15,750 c.p.s.(525 lines and 30 frames). Overall ΔT allowed = 1,000 μsec. at L.F. end

= 0.1 μ sec. at H.F. end]

The video frequency range being very large it is very difficult to obtain constant gain and constant time delay over the wide band used. So a compromise is made with both the gain and

(Reference : No,3,4)

phase satisfactorily near the ideal. Besides, the factors that control the response of the amplifiers at one end of the range, have practically no effect on the other end. So it will be convenient to discuss the problem of video amplification in two steps:

i) H.F. compensation
ii) L.F. compensation

H.F. compensation is considered in this chapter.

H.F. considerations:

From the simple circuit with a pentode it is clear that

$$\text{Gain } (G) = g_m Z_L \quad \cdots \quad (1)$$

where Z_L = the impedance of the parallel equivalent circuit.

g_m = transconductance of the tube

$\therefore$ If Z_L is decreased by the reactance of the shunt capacitances like wiring, socket, and tube etc., the gain is reduced. This happens at H.F. as the reactances diminish at H.F.; the relation between the reactance and H.F. being:

$$X_c = \frac{1}{2\pi f C} \quad \cdots \quad (2)$$

C is generally small

This drop in gain is accompanied by the phase delay it being given as

$$\phi = -\tan^{-1} 2\pi f C_T R_L \quad \cdots\cdots \quad (2a)$$

So in order that the amplifier should be good for video amplification these defects should be remedied and the means are desired to reduce these effects of load circuit capacitance. There are two popularly used means to compensate these defects:

i) Use of a small resistor (load) whose resistance $<< X_c$ of the shunt capacitance at the highest frequency of the video,

Reference : No. 9,4

band. So the phase and gain characteristics are made quite free of X_c.

ii) A circuit with an inductance to counteract the coupling condenser. The gain is constant and the plate load resistor (R_L) in unchanged.

These means used to increase the video frequency band with constant gain and uniform phase delay are called the correction circuits and are classified as:

i) Uncompensated circuit

ii) Compensated circuit - shunt peaking

iii) Compensated circuit - series peaking

iv) Shunt-series peaking

From the (1) expression for gain it is clear that G is not constant, for uncompensated circuit over the wide band unless

$$R_L << X_{c_T} \quad \text{at } f_{max.}$$

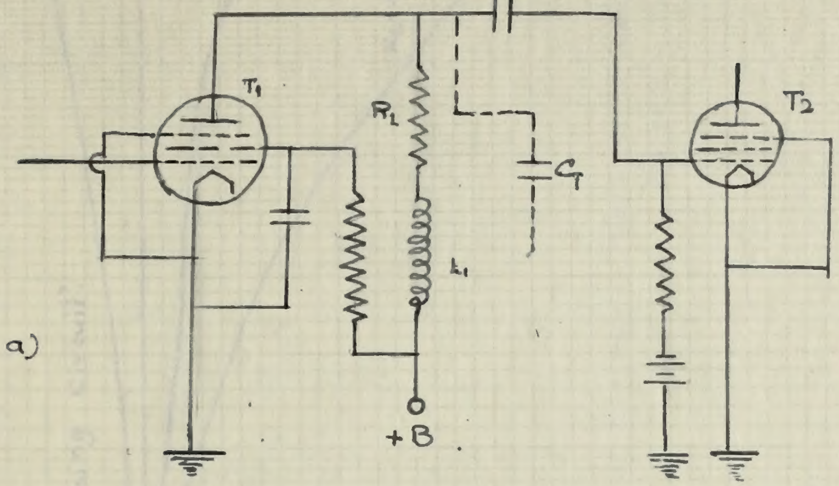
where f_{max} = max. video frequency

So this circuit is unsuitable for video amplification and is not discussed in detail.

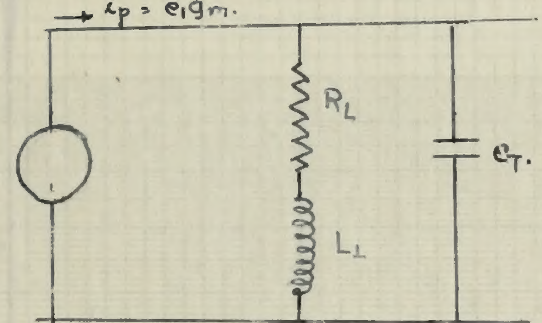
The inductance (L), used to compensate the effect of the shunt capacity forms a resonant circuit with the shunt capacity at a frequency greater than f_{max}, the rising resonance characteristic being used to counteract the falling off, of the load impedance (Z_L). at the upper frequency limit (f_{max}). So the resistive load should be so chosen that the gain in the mid-frequency range where the effects of reactive elements are not prominent will be the same as that at H.F. As seen above, the total shunt capacity (C_T) is the factor that disturbs the work-

Diagram. 25

a)



b)



" Shunt Peaking Circuit, with its H.F. Equivalent Circuit."

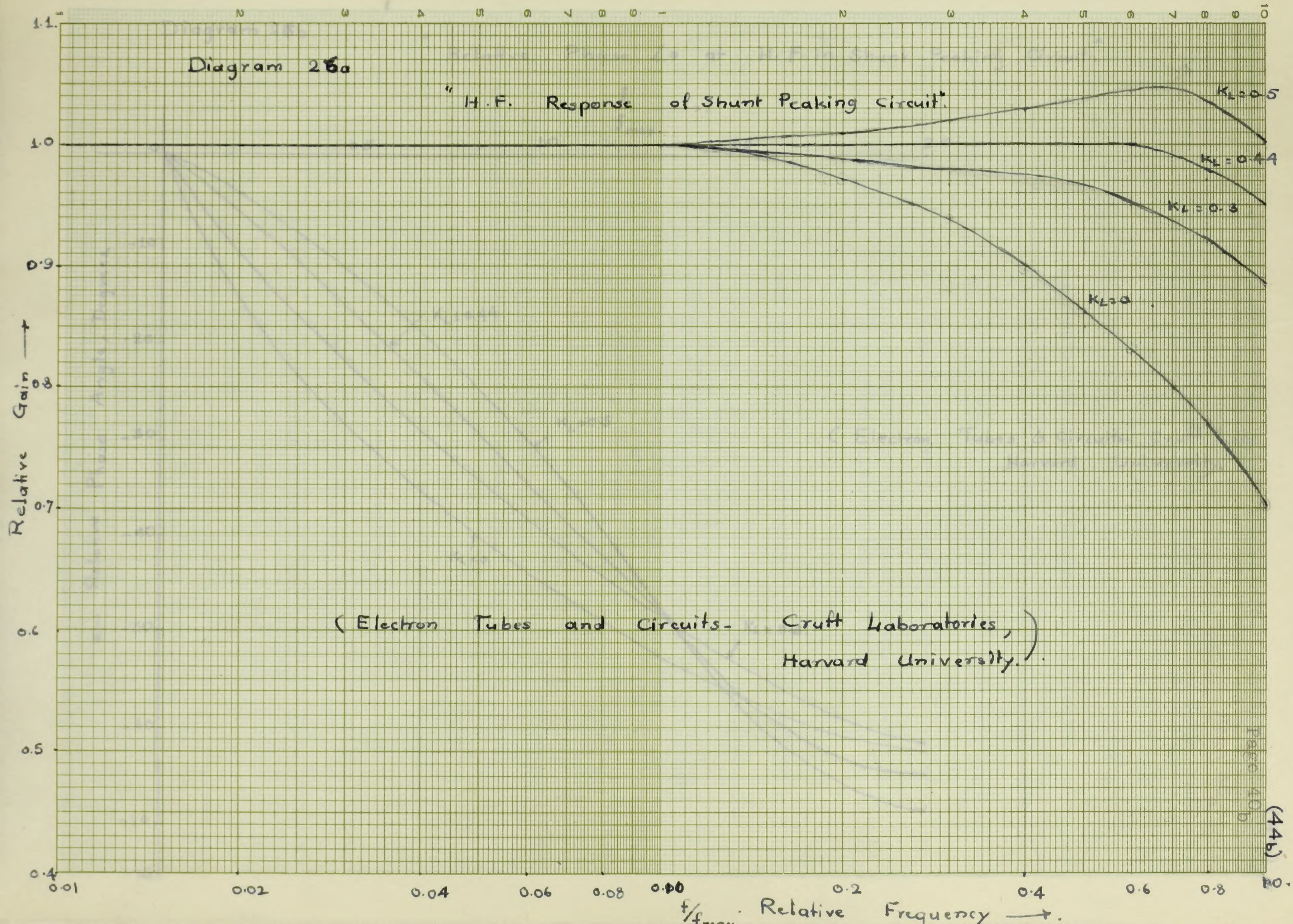
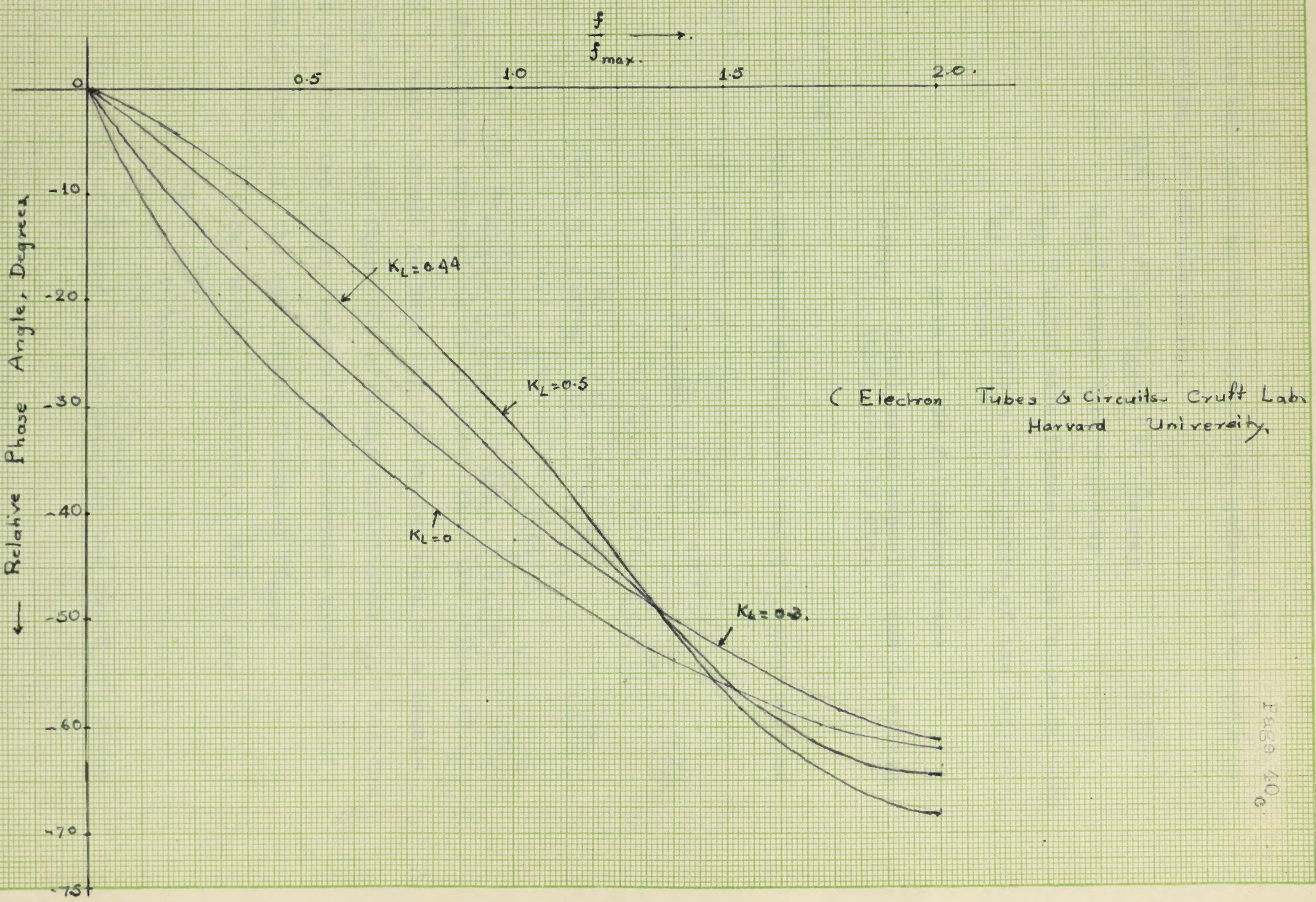


Diagram 26a
"H.F. Response of Shunt Peaking Circuit".
$K_L = 0.5$
$K_L = 0.44$
$K_L = 0.3$
$K_L = 0$
(Electron Tubes and Circuits- Cruft Laboratories, Harvard University).
Relative Gain →
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
f/f_{max}. Relative Frequency →.
0.01
0.02
0.04
0.06
0.08
0.10
0.2
0.4
0.6
0.8
1.0

Diagram 26b.

"Relative Phase ∠s at H. F. in Shunt Peaking Circuit."



ing of the amplifier so the compensation generally consists in counteracting the effects of C_T.

$$C_T = C_{gk} + C_{pk} + C_{gp}(G+1) + C_{stray} \qquad (3)$$

C_{pk} = output tube capacity

C_{gk} = input capacitance of the following tube

C_{gp} = grid-plate capacitance of the following tube

G = gain of the following stage

C_{stray} = Total shunt capacity due to wiring, tube, sockets etc.

Shunt-peaking:

It is the most widely utilized H.F. compensation circuit

$$G = g_m |z| \text{ at frequency } 'f' \; \ldots \qquad (4)$$

$$\text{where} \quad Z = \frac{\frac{R_L}{2\pi f C_T} + j\left(\frac{L_1}{C_T} - 4\pi^2 f^2 L_1^2 - R_L^2\right)}{2\pi f C_T\left[R_L^2 + \left(2\pi f L_1 - \frac{1}{2\pi f C_T}\right)^2\right]} \; \ldots \qquad (4a)$$

$$\therefore G = g_m \frac{\sqrt{\frac{R_L^2}{4\pi^2 f^2 C_T^2} + \left(\frac{L_1}{C_T} - 4\pi^2 f^2 L_1^2 - R_L^2\right)^2}}{2\pi f C_T\left[R_L^2 + \left(2\pi f L_1 - \frac{1}{2\pi f C_T}\right)^2\right]} \; \ldots \qquad (5)$$

$$\text{and} \quad \phi = \tan^{-1} \frac{f}{1/2\pi C_T R_L}\left[\left(\frac{L_1}{C_T R_L^2} - 1\right) - \frac{L_1^2}{C_T^2 R_L^4} \frac{f^2}{1/(2\pi C_T R_L^2)^2}\right] \; \ldots \qquad (5a)$$

From these expressions it is clear that the values of L_1 and R_L, which should be used for the design work of a shunt-peaking circuit are functions of shunt-capacitance C_T. Besides these factors, the other factors that determine the values of R_L and L_1 are : i) the max. video frequency (f_{max})

ii) the design constants k_R and k_L are

$$k_R = \frac{R_L}{1/2\pi f_{max} C_T}$$

$$k_L = 2\pi f_{max} . L_1 / {}^1/_{2\pi f_{max} C_T} .$$

In terms of k_L and k_R the gain and the phase are given as:

Reference : Nos. 1, 3, 4, 8, 9.

$$\text{Gain} = g_m \frac{R_L\left[1 - j\left\{k_L^2 (f/f_{max.})^3 + (1-k_L)(f/f_{max.})\right\}\right]}{(f/f_{max.})^2 + \left[k_L (f/f_{max.}) - 1\right]^2} \quad \ldots \quad (6)$$

if $k_R = 1$

and $$\phi = \tan^{-1} k_R \frac{f}{f_{max.}} \left[\left(\frac{k_L}{k_R^2} - 1\right) - \frac{k_L^2}{k_R^4}\left(\frac{f}{f_{max}}\right)^2\right]$$

$\therefore$ for $k_R = 1$

$$\phi = \tan^{-1} \frac{f}{f_{max}} \left[(k_L - 1) - k_L^2\left(\frac{f}{f_{max.}}\right)^2\right] \quad \ldots \quad (6a)$$

(The values of k_R range from 0.8 to 1.0 while those of k_L vary from 0.3 to 0.7). Most of the designers utilize the following values of k_R and k_L which is equivalent to making the resonant frequency (f_r) of C_T and L_1:

$$f_r = 1.41 f_{max} \quad \ldots \quad (7)$$

when $k_R = 1.0$; $k_L = 0.5$ .... (A)

The design equations are:

$$\left.\begin{aligned} R_L &= \frac{1}{2\pi f_{max.} C_T} \\ L_1 &= 0.5\, C_T R_L^2 \\ &= \frac{1}{8\pi f_{max}^2 C_T} \end{aligned}\right\} \quad \ldots \quad (8)$$

These equations give the required values of C_T and R_L for a required f_{max}.

<u>Illustration:</u>

Consider 1851 pentode tubes with total load circuit capacitance C= 25 $\mu\mu$f. with f_{max} = 3 m.c.p.s.

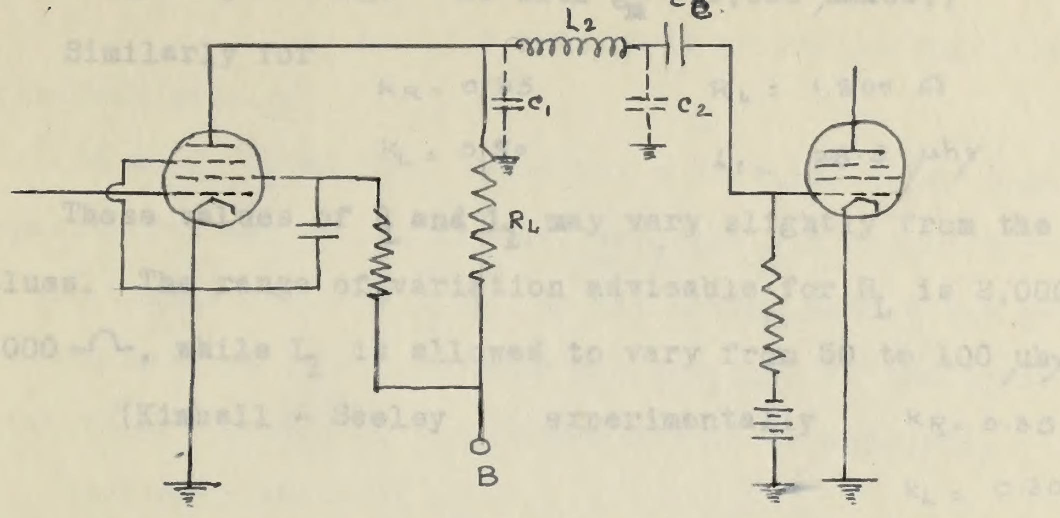
So for the values of k_R AND k_L generally adopted (A)

$R_L = 2,120\ \Omega$

$L_1 = 50\ \mu$hy.

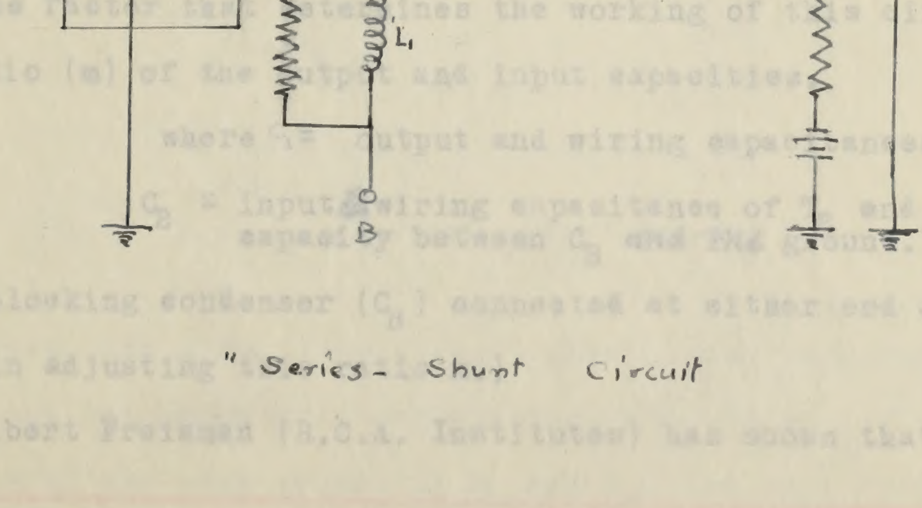
Reference: Nos. 8, 9.

Diagram 27



"Series - Peaking Circuit".

Diagram 28



"Series - Shunt Circuit

performance of this compensation the C_2 should be at least twice the value of C_1 or $C_2 \geq 2C_1$

$\therefore m \geq 2$ (a condition generally fulfilled in practical sets.)

If $m < 2$, C_B IS USED to adjust m to equal 2; or some small capacitances may be put across the input and output terminal of the filter (ie., of L_2). By the latter method the gain is lowered because G is inversely proportional to the load circuit total capacitance. So the former method is employed.

Necessary value of L_2:

Let f_r be the resonant frequency of C_1 and L_2

$$\therefore f_r = \frac{1}{2\pi\sqrt{L_2 C_1}} \quad \text{by def.}$$

& generally $f_r = \sqrt{2}\, f_{max.}$, the top frequency

$$\therefore L_2 = \tfrac{1}{2}(2\pi f_{max})^2 C_1$$

$$\therefore 2\pi f_{max.} L_2 = \frac{1}{2(2\pi f_{max})C_1}.$$

$$\therefore X_{L_2} = X_{C_1}$$

Again $\because m = 2$, for perfect compensation.

$$R_L = \frac{1 \cdot 5}{2\pi f_{max.}(C_1+C_2)}$$

$$\text{and } L_2 = \frac{2}{3}(C_1+C_2)R_L^2$$

$\therefore$ The design equations are :

$$\left.\begin{aligned} R_L &= 1\cdot5/2\pi f_{max.}(C_1+C_2) \\ L_2 &= \tfrac{2}{3}(C_1+C_2)R_L^2 \end{aligned}\right\} \cdots (9)$$

(Sometimes, the high plate circuit capacitance required to be worked out into a low-grid capacitance. So use m= 1/2 instead of m=2 with the same values of R_L and L_2 ; the only difference

Reference : Nos - 1, 3, 4, 8, 9

between the connections in two cases is that R_L is connected across the smaller terminating capacitance.)

For any "m" and $f_{max} = 0.707 f_r$.

$$\left.\begin{aligned} R_L &= 1/\sqrt{2}\, m\, \omega_0 C_1 \\ L_2 &= 1/2\,\omega_0^2 C_1 \end{aligned}\right\} \text{ where } \omega_0 = 2\pi f_{max}.$$

From this discussion it is clear that:

G_{series} = 50% greater than G_{shunt} for the same f_{max} and C_T $(= C_1 + C_2)$

and ΔT series $<$ ΔT shunt

Particular case: $\Delta T_{shunt.} = \frac{0.231}{3} = 0.077$ for $f_{max.} = 3$ m.c.p.s.

$\Delta T_{series.} = 0.0113/3 = 0.004$ for $f_{max.} = 3$ m.c.p.s.

So the series circuit is more advantageous than the shunt-peaking, if and only if, m can be adjusted ≥ 2 without appreciable decrease in gain, below that of the shunt-peaking. If $m < 2$ there are peaks at the H.F. end of the gain characteristics and this is undesirable effect; except when the H.F. gain in other stages is deficient.

Series-shunt circuit: It is clear from the separate discussions of ~~two~~ circuits that under the same working conditions the series circuit has a greater gain and lesser time-delay variations while the shunt peaking has ~~the~~ capability to work beyond f_{max} used. So if these two are combined together, an overall advantageous compensation circuit is obtained. It is called the series-shunt circuit.

In this circuit the R_L for a constant gain up to f_{max} with a given C_T is approximately , ... is greater than that in the case of shunt-peaking circuit.

(R.C.A. Reviews; Nos 4, 3.)

Gain per stage = 80% greater gain per stage than for
the shunt-peaking circuit.

and the time delay variations are approximately the same as the series-peaking circuit. The circuit design equations are:

For $\frac{C_2}{C_1} = m = 2$;

$$R_L = \frac{1.8}{\omega_0 (C_2 + C_1)} \; ; \; L_1 = 0.12 \, (C_1 + C_2) R_L^2$$

$$L_2 = 0.52 \, (C_1 + C_2) \, R_L^2 .$$

Circuit no.	Type of H.F. compensation	R_L / $\frac{1}{2\pi f_{max} C_T}$	ΔT μ sec.	L_1 μhy	L_2 μhy	$C_2/C_1 = m$
1	None	1	$0.035/F_{max}$	-	-	-
2	Shunt	1	$0.231/f_{max}$	$0.5C_T R_L^2$	-	-
3	Series	1.5	$0.0113/f_{max}$	-	$0.67R_L^2 C_T$	2
4	Shunt-series	1.8	$0.015/f_{max}$	$0.12C_T R_L^2$	$0.52C_T R_L^2$	2

From these discussions it is clear that the last one has the greatest gain (constant upto the f_{max}) available with the smallest variations of time delay from the value permissable.

(Reference : No. 4.)

"L.F. Compensation".

Diagram 28.

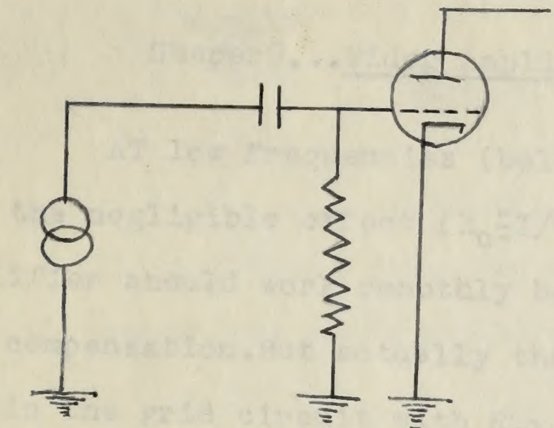
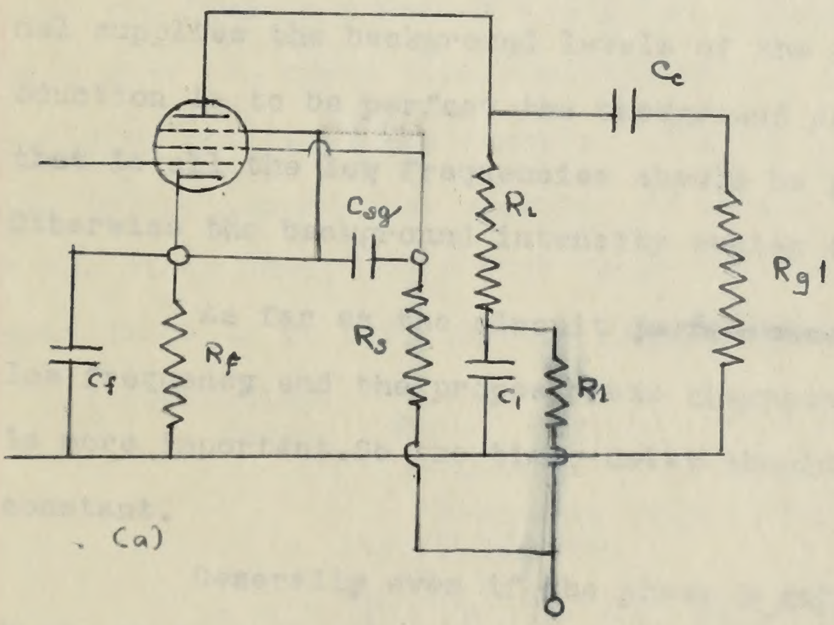


Diagram 30 - "Low Frequency Compensation Circuit".



(Seeley - Kimball.)

$R_L = 2,000\ \Omega$

$R_F = 150\ \Omega$

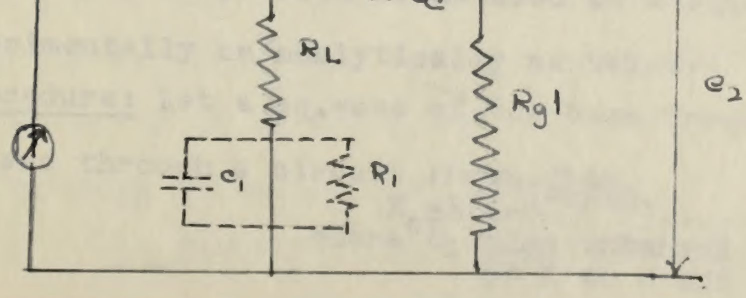
$R_1 = 2,500\ \Omega$

$C_F = 25\ \mu f$

$C_1 = 15\ \mu f.$

R.C.A. 1851 tube

(a)



(b) Parallel - Plate - Equivalent Circuit.

Chapter8...Video Amplifiers,L.F.Considerations.

AT low frequencies (below IO K.C.)the shunt capacitance has the negligible effect ($X_c = I/wC$),so a standard video signal amplifier should work smoothly between IOOto 200k.c.with or without compensation.But actually they do not as the blocking condenser in the grid circuit with R_{g1} does not pass the L.F.signal undistorted.

In the production of a picture the L.F.of the video signal supplies the background levels of the picture.So if the reproduction is to be perfect the background detail should be clear; that is all the low frequencies should be passed without distortion. Otherwise the background intensity varies from top to bottom.

As far as the circuit performance is concerned at the low frequency end the proper phase characteristic maintainence is more important.So the time delay should be either zero or constant.

Generally even if the phase & gain characteristic are known it is very difficult to predict the performance of the tube at L.F. So the problem is handled on a square wave basis,either experimentally or analytically as below:

Procedure: Let a sq.wave of the base frequency = 60 c.p.s. be passed through a circuit shown.Then

$$E_c = E(I-e^{-t/cR}) \text{...................} (I)$$

where t = time interval between the application of E to c and R.

If the time constants of the circuit are large (ie., where the current through R is essentially constant, for a short interval following the application of the pulse.)

then $\frac{E_c}{E} = \frac{t}{cR}$ . . . . (2)

so $\frac{E_c}{E} \times 100 = \frac{t}{cR} \times 100$ . . . . (3)

$\frac{E_c}{E} \times 100 =$ drop in amplitude of the square wave in "t". (It is obvious from the equation that the amplitude of the pulse approaches the average value.) If the distortion is present the longer pulse has lesser slope than a short one.)

From the equation (3) it is clear that if a % drop is known, the required values of C and R can be evaluated by letting "t" equal the time duration of the pulse. Though any values of C and R give the known time constant values, the extreme values should be avoided. For example, if R is large the d.c. bias will be influenced considerably; if grid-current is present, on the other hand, low R with large C increases the total load capacitance C_T at H.F. thereby affecting the H.F. response.

Illustration:
Data: Basic frequency of a Sq. Wave = 60 c.p.s.
Capacity (C) = 0.25 μf.
Resistance (R) = 0.5 megΩ.
$\therefore t = 1/120$ sec.

$$\therefore \frac{E_c}{E} = \frac{t}{cR} = \frac{1}{120} \times \frac{1}{0.25} \times \frac{1}{0.50} = 6.7\% = \%\text{ amplitude drop.}$$

On the contrary, on the relative voltage response basis at 60 c.p.s. the response at 60 c.p.s. is found tobe better than 99.9% the response with infinite time constant. So it indicates the necessity of checking the L.F. response on square wave basis.

Factors affecting L.F. response:

The following factors are the most important ones,

(Ref: R.C.A. Reviews.)

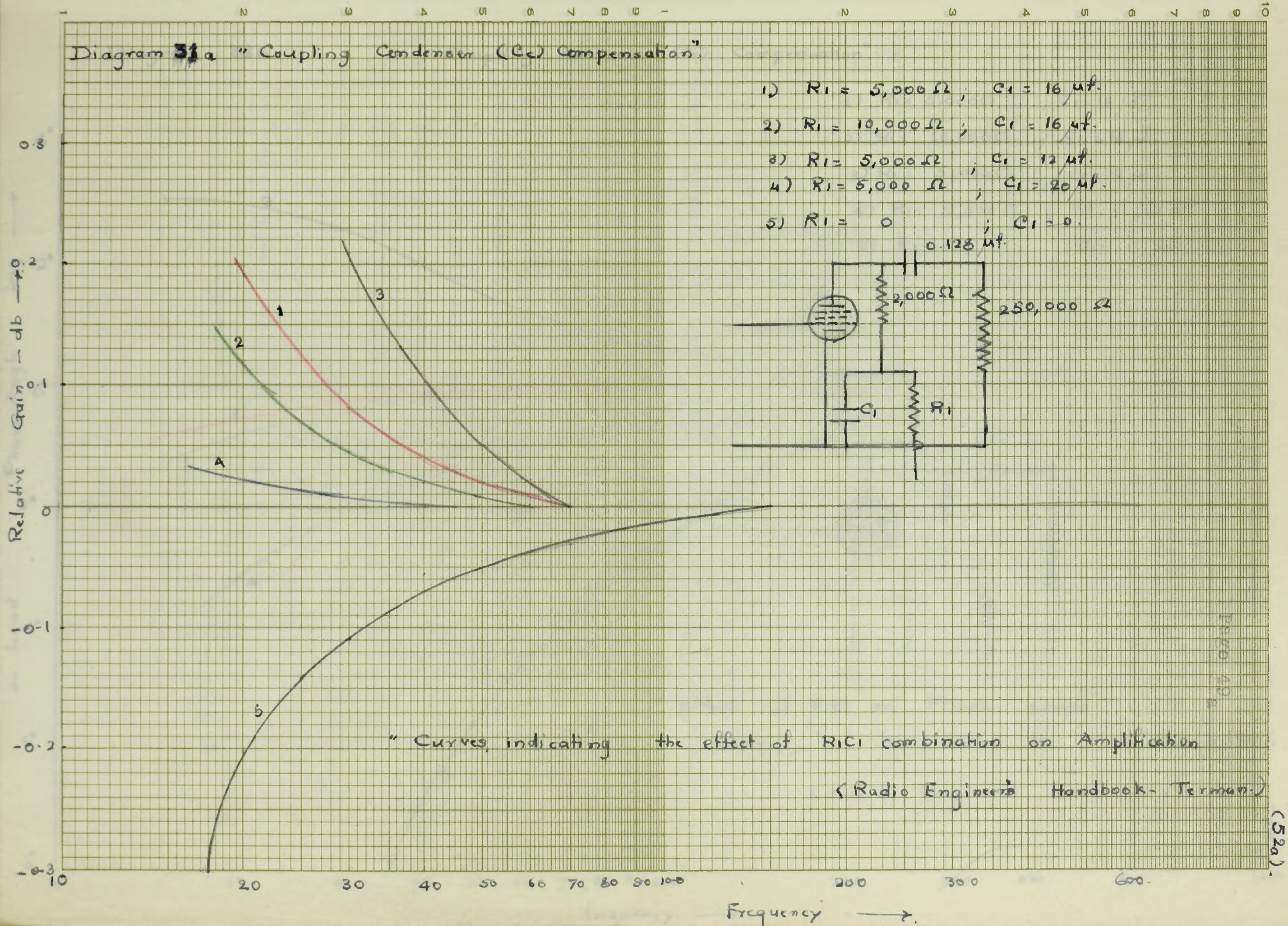


Diagram 31a " Coupling Condenser (Cc) Compensation".

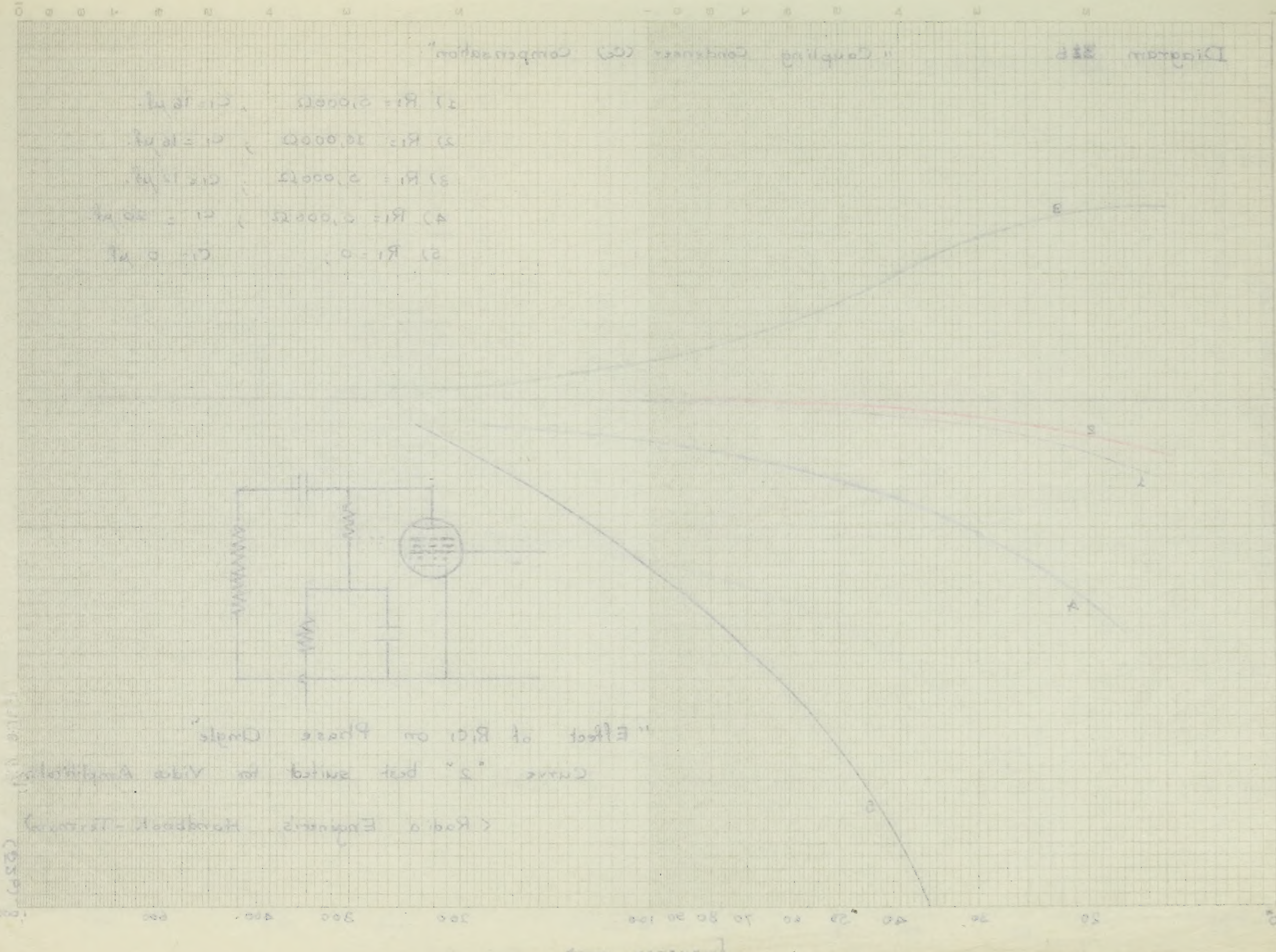


Diagram
"Coupling Condenser (Cc) Compensation"
1) R1 = 5,000Ω , C1 = 16 μf.
2) R1 = 10,000Ω , C1 = 16 μf.
3) R1 = 5,000Ω , C1 = 12 μf.
4) R1 = 2,000Ω , C1 = 20 μf.
5) R1 = 0 , C1 = 0 μf
"Effect of R1C1 on Phase Angle"
Curve "2" best suited for Video Amplifiers.
(Radio Engineers Handbook - Terman)
Frequency

that affect the response of an amplifier (video) at L.F. :

i) The coupling condenser (C_c)

ii) The bias impedance

iii) The screen grid circuit impedance.

The coupling condenser

Generally in practice pentodes are used for video amplifiers and the grid-leak resistance (R_{gl}) is so much larger than the coupling resistance (R_L) $\quad R_{gl} >> R_L \ldots\ldots$ (4).

From the circuit diagram it is seen that

$$G = \frac{g_m R_L . R_{gl}}{\sqrt{R_{gl}^2 + X_{c_c}^2}} = \frac{g_m R_L}{\sqrt{1+\left(\frac{X_{c_c}}{R_{gl}}\right)^2}} \quad \ldots\ldots \quad (5)$$

$$\text{and } \quad \phi = \tan^{-1}\frac{X_{c_c}}{R_{gl}} \quad \ldots\ldots \quad (5_a) \quad \text{where } X_{c_c} = \frac{1}{2\pi f C_c}.$$

From (5) and (5_a) it is clear that C_c, the coupling condenser, affects the phase shift (lead) more than the amplification (falling). The tolerable phase shift at 60 c.p.s. is 2^o so in order to maintain the shift within the limit at f=60 c.p.s. $\quad R_{gl} C_c > 0.076 \ldots\ldots\ldots$ (6)

$$\left(\because \frac{2\pi}{180} \text{ rad.} = \tan^{-1}\frac{1}{2\pi \times 60 \times R_{gl} C_c} . \right)$$

The condition (6) is obtained by the use of large condenser capacity and grid leak resistor; a parallel combination $R_1 C_1$ is used in series with R_L instead.

With the $R_1 C_1$ combination used: $\quad e_2$ = output voltage $= e_1 g_m Z_3$

where Z_3 = impedance of equivalent circuit with R_1C_1 included.

$$\therefore e_2 = e_1 g_m Z_3 = e_1 g_m \frac{R_L + Z_1}{R_L} . Z_2 \ldots\ldots\ldots \quad (7)$$

where Z_2 = impedance of equivalent circuit without R_1C_1 combination.

Z_1 = impedance of $R_1 C_1$.

Reference : No. 2.

Various effects, observed in Cathode Impedance Compensation.

Diagram 32_a

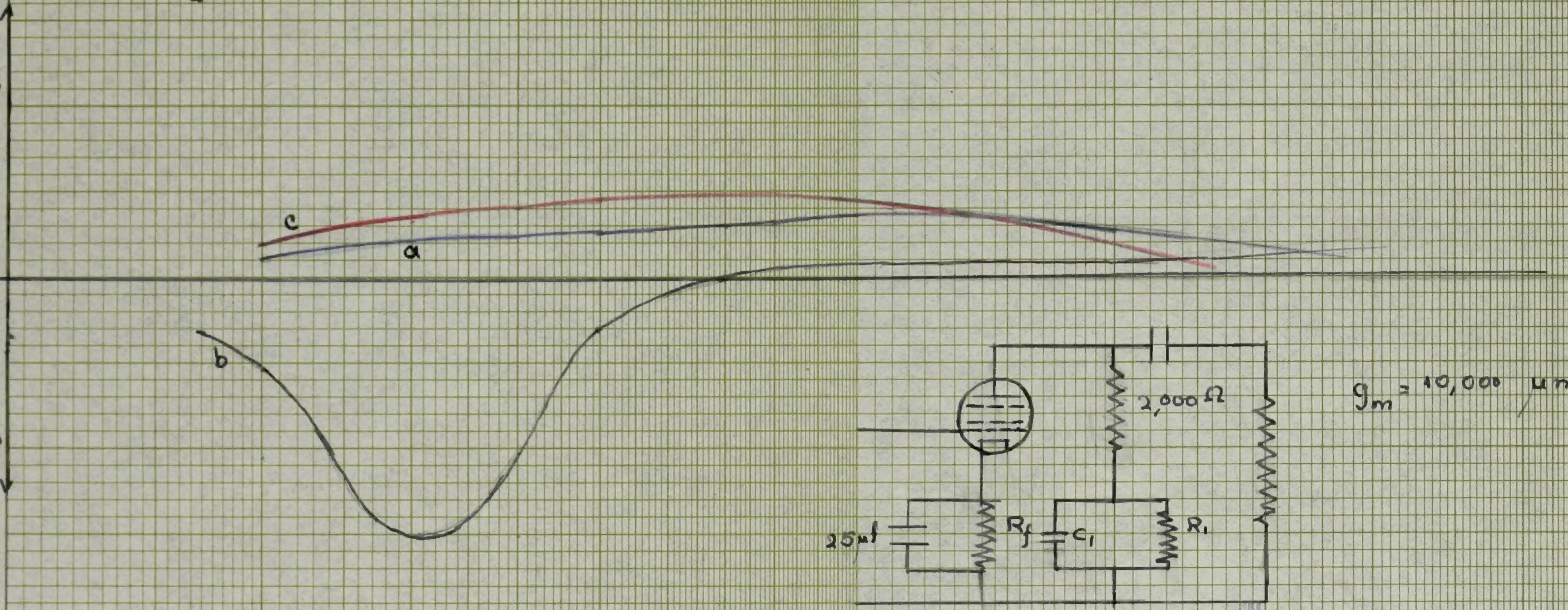
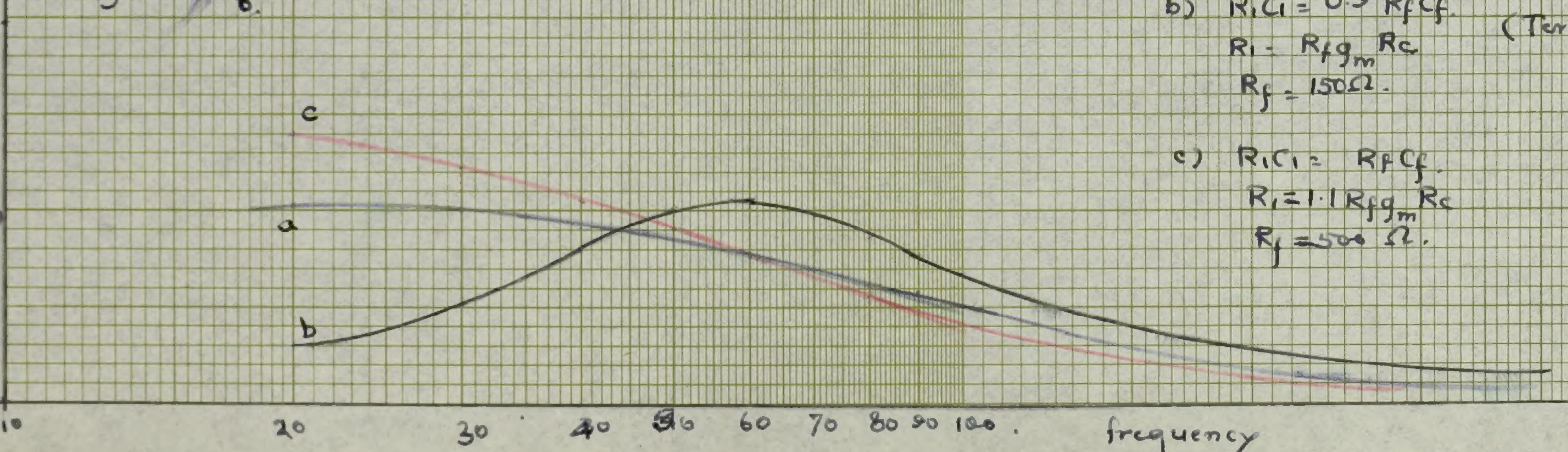


Diagram 32_b.



a) $R_1C_1 = R_fC_f$,
$R_1 = 1.1\,R_f\,g_m R_c$.
$R_f = 150\,\Omega$

b) $R_1C_1 = 0.9\,R_fC_f$.
$R_1 = R_f g_m R_c$
$R_f = 150\Omega$.

c) $R_1C_1 = R_fC_f$.
$R_1 = 1.1\,R_f g_m R_c$
$R_f = 500\,\Omega$.

Curve "a" serves the as the best characteristic for Video Amplification

(Terman. Radio Engineers Handbook.)

Exp. (7) shows that the output increases by a factor $\frac{R_L + Z_1}{R_L}$ but it lags by an amount corresponding to the angle, by which the impedance of (Z_1, R_L) combination is leading.

Ideal compensation requirements:

$$R_{g1} C_c = R_L C_1 \ ; \ R_1 = \infty \quad \ldots\ldots \quad (8)$$

In practice $R_1 \geq 10/\omega C_1$ serves the purpose.

The curves plotted show that as R_1 is increased the gain becomes more uniform so also the phase shift is varied uniformly. (Curves 1, 2, and 5 indicate this situation.) If C_1 is varied R_1 being held constant; the smaller the value of C_1 the greater is the gain and more lagging is the phase. (The curves 1 and 3, if compared, prove this fact.) Conversely, larger C_1 makes the phase leading and gain to drop. (Comparison 1 and 4 indicate this.)

The bias impedance:

The output of an amplifier is affected by the bias-impedance ($R_F C_F$). It is reduced and leads in phase. So in order that the amplifier should work perfectly, this bias-impedance requires to be eliminated. Though $R_F C_F$ can be eliminated by changing the bias-supply means, it is not generally undertaken as it is a little complicated. This bias-impedance effect can be easily compensated with the help of the compensating combination ($R_1 C_1$):

$$\text{Relative Output at L.F.} = \frac{1 + \frac{Z_1}{R_L}}{1 + g_m Z_F} \quad \ldots\ldots \quad (9)$$

where Z_1 = impedance of $R_1 C_1$.

Z_F = impedance of $R_F C_F$ circuit.

R_L = Coupling Resistor.

(Without $R_1 C_1$ circuit: $e_o^1 = e_1 g_m \frac{R_{g1}(R_L + Z_F)}{(R_L + Z_F) + R_{g1}}$.

with $R_1 C_1$ circuit: $e_o^2 = e_1 g_m \frac{(R_L + Z_F + Z_1) R_{g1}}{R_L + Z_F + Z_1 + R_{g1}}$.)

Reference: No. 2.

$\therefore$ For two outputs to be the same:

$$\frac{1+Z_1/R_L}{1+g_m Z_F} = 1$$; This can be reduced to

the following conditions:

$$\left.\begin{aligned} R_1C_1 &= R_F C_F \\ \text{and}\quad C_1 &= C_F/g_m R_L \end{aligned}\right\} \quad \ldots\ldots \quad (10)$$

These are the conditions for perfect compensation. The graphs drawn indicate the validity of these conditions as requirements for compensation of $R_F C_F$.

The screen-grid impedance:

In most practical cases, the screen-grid voltage is supplied through a resistor R_{sg}, by-passed by a condenser C_{sg}. So an impedance is introduced which affects the amplifier working in the same fashion as the coupling condenser. (C_c), discussed above. As, in the case of C_c the max. phase shift allowed is 2^o at 60 c.p.s. and the necessary condition for perfect compensation is: $R_{sg}.C_{sg} > 0.076$ . . . (12).

Rules to be observed in L.F. compensation:

1) The effects discussed above should be compensated individually and thoroughly for a single stage rather than for the whole system.

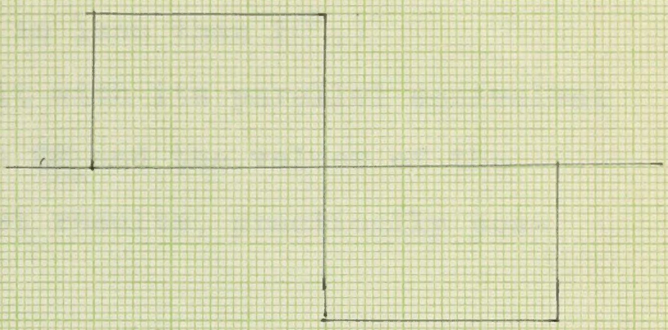
2) The coupling condenser effect and the s creen grid impedance effect should be compensated in different stages. So, in practic, these two effects are minimized by the introduction of proper bias-impedance. Afterwards, every group of five stages has one stage with no bias impedance. In this stage the effects of C_c and the screen-grid impednance of all stages, are

Reference. No. 2.

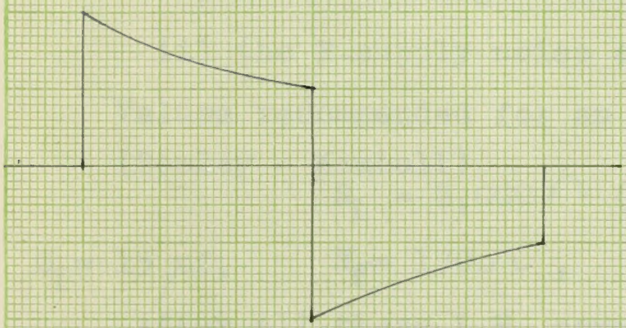
Diagram 33.

"Effects of Amplifier Imperfections, on an Ideal Sq. Wave".

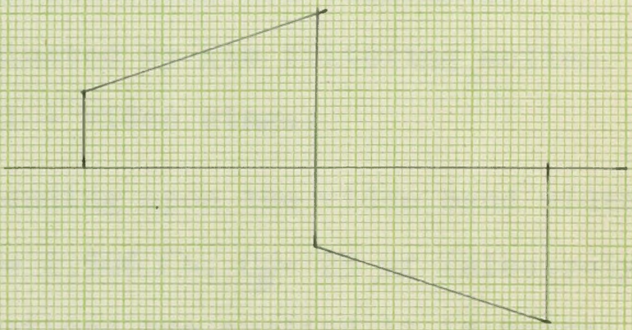
a) Input Wave



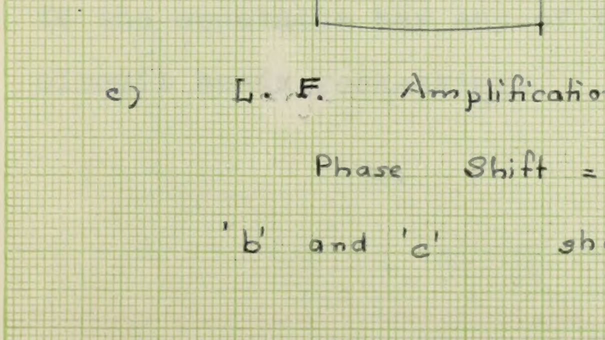
a) Input Wave



b) Phase leading at L.F.

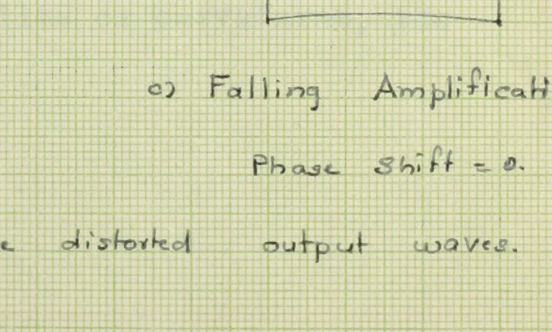


b) Phase lagging at L.F.



c) L.F. Amplification

Phase Shift = 0



c) Falling Amplification

Phase Shift = 0.

'b' and 'c' show the distorted output waves.

(Radio Engineers' Handbook - F.E. Terman.)

eliminated by means of $R_1 C_1$ combination of required value. (This procedure of combination is effective until the total phase shift requiring correction is less than 2 $^{\circ}$.)

The L.F. compensation circuit with its parallel equivalent circuit is shown in diagram 36a and 36b and the values of the circuit elements required for best results, practically possible, are listed therein.

The value of $R_1 = 10{,}000\Omega$ indicated, gives a perfect L.F. response up to as low as 20 c.p.s.

Advantages of L.F. compensation circuit:

i) motor-boating or L.F. oscillations are eliminated

ii) the B-supply noise eliminated by its filtering action

Values recommended for an 1851 - video stage:
(Seeley - Kimball)

$R_L = 2{,}000\Omega$ (depending upon the video band width)

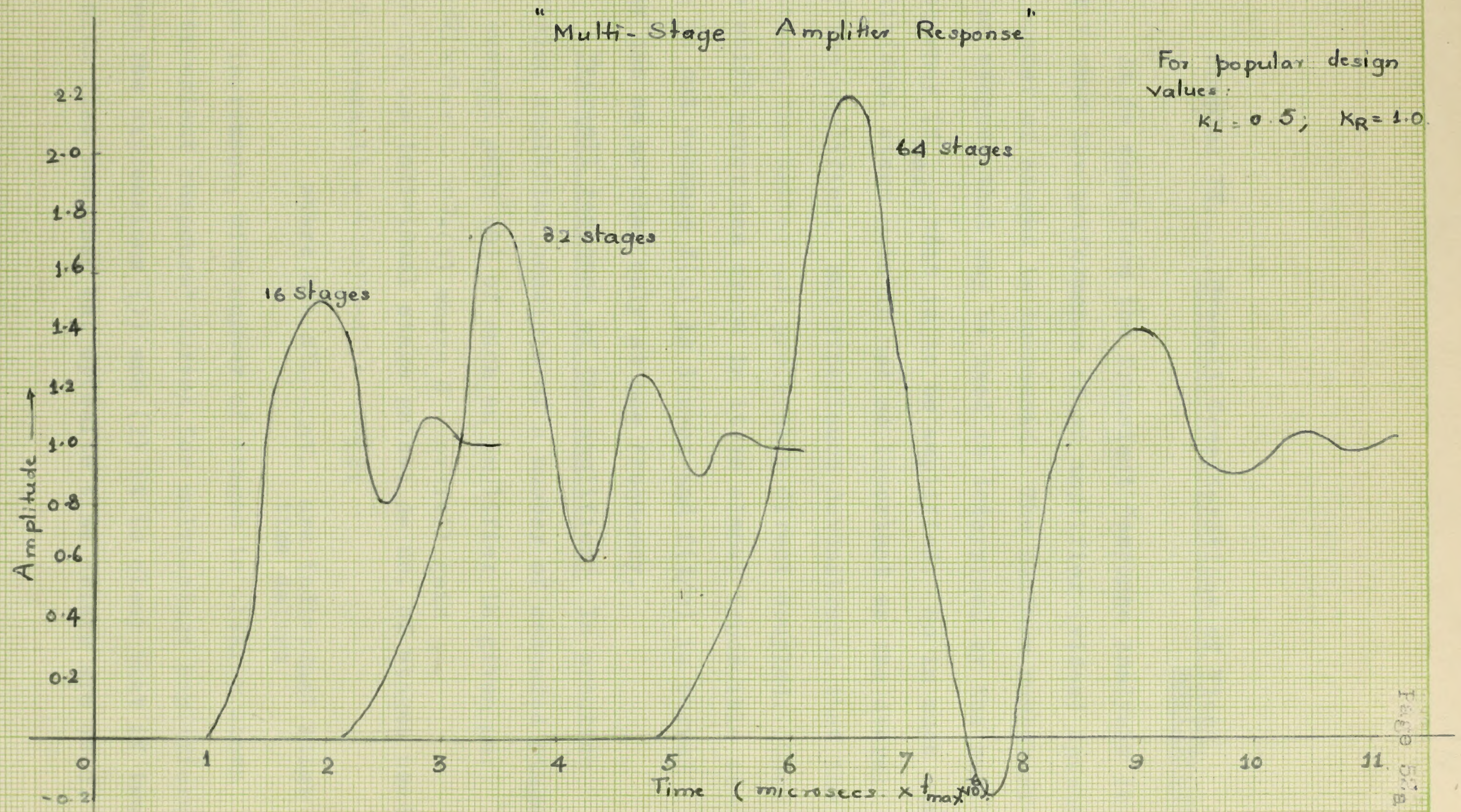
$C_1 = 15\mu f$, $R_f = 150\Omega$, $R_1 = 2{,}500\Omega$, $C_f = 25\mu f$ (electrolytic)

After all these L.F. compensations are applied it is necessary to check the apparatus for its accuracy. So a square wave is applied to check for distortion.

The tilt of the horizontal part of the output is due to the phase change of the fundamental frequency, as in "b" while the variable gain characteristic produces the curvature of the output (in "C"). So if the output of the square wave applied to the apparatus has any of these tilts or curvatures, the circuit needs rechecking.

(Ref: R.C.A. Reviews.)

Diagram 34.



(Television - Zworykin & Morton.)

Chapter IX.....Overall Considerations of Video Amplifiers

It is seen from the Transient Response Analysis in chapter V that the performance of an amplifier (video) increases as the number of stages is increased. The maximum number of tubes (or stages) that may be used is determined by the maximum frequency (f_{max}) that is to be amplified. So in such cases the individual stage gain is not so important as the overall gain of the amplifier. But experience demonstrates that the fewer stages the better and preferably direct coupled. Once a phase shift error has crept in it is almost impossible to balance it out because f(c) is linear and f(1/c) is curved and they can be matched only at one frequency.

Over-all response of the amplifier: In practice a television amplifier consists of a number of cascaded stages, and the overall gain (G) of such an amplifier is given as:

$G = G_1 \times G_2 \times \cdots \times G_n$ (1) where G = overall gain

$G_1, G_2, \ldots G_n$ = individual stage gains; n= no. of stages used;

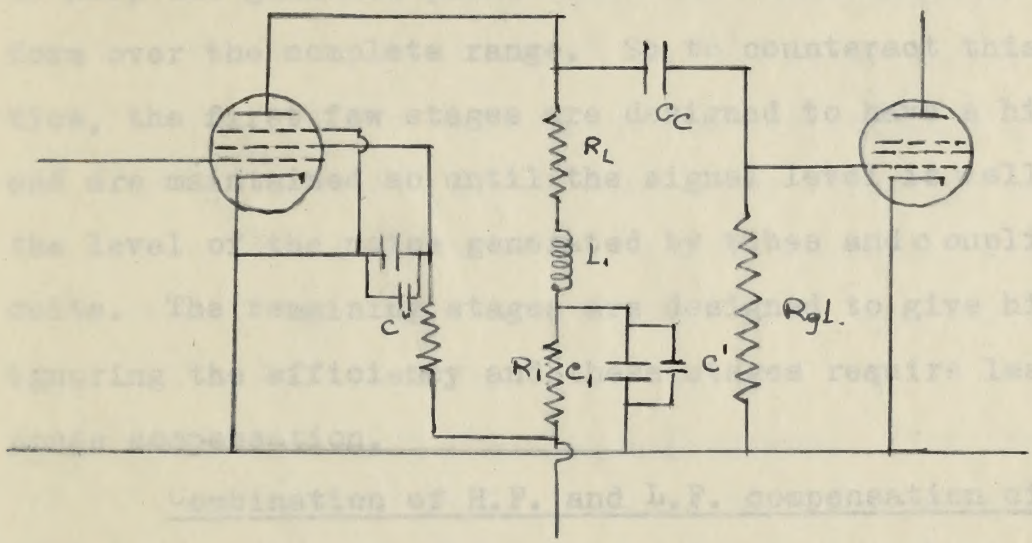
and ΔT (overall) $= n(\Delta T_1 + \Delta T_2 + \cdots + \Delta T_n)$ (2)

where $\Delta T_1, \Delta T_2, \ldots \Delta T_n$ are individual stage time delays

(The gain increment, with number of stages is clearly shown by the "transient response" curves for multi-stage amplifiers.)

From the expressions (1) and (2) it is clear that if two stages with flat response but opposite time delays are used,

Diagram 35. " Combined H·F· & L·F· Equalisation Circuit".



L_1 = Shunt Peaking Inductance

C, C" = Small condensers, to by-pass H·Fs.

R_1C_1 = L·F Equalisation Network.

(Radio Engineers' Handbook – F.E. Terman.)

the overall working of the amplifier is much improved and is better than two identical stages. This is generally utilised in the practical design of a video amplifier. As the video range is from 60 c.p.s. to 4 m.c.p.s., it is very difficult to keep the gain and phase characteristics constant or uniform over the complete range. So to counteract this in practice, the first few stages are designed to have a high gain and are maintained so until the signal level is well above the level of the noise generated by tubes and coupling circuits. The remaining stages are designed to give high f_{max} ignoring the efficiency and these stages require less response compensation.

Combination of H.F. and L.F. compensation circuits: Though the separate compensation circuits can be combined to give satisfactory performance in any way, care should be taken in their combination. It should be observed while combining, that the H.F. compensation circuit does not affect the L.F. responses, otherwise, the circuit as a whole is of no practical use. So the combination shown in the diagram is utilised.

It clearly indicates that at L.F. the H.F. circuit is just a resistive load, while at H.F., the L.F. compensation circuits do not operate at all. So the two circuits are completely independent of each other. (L.F. circuits are inoperative at H.F. as they are shunted by capacitances.) Sometimes small mica-capacitances (0.001 to 0.01 μf) are used across the capacities used in the circuit. These help in ensuring a low impedance to higher video frequencies in case the capa-

cities in the circuit are large. Sometimes large condensers possess a certain amount of inductance so it is required to shunt the equalizing condenser in the plate circuit and also the bias and screen by-pass condensers. So the mica condensers are used. (In our present case, the shunt-peaking is used, as it is the most advantageous one and is popularly used. It is known that the series-peaking circuit has a greater and constant gain and lesser time delay variation than that for shunt-peaking circuit; but the shunt-peaking circuit gives amplification at frequencies higher than top frequency (f_{max}) while the other one does not.)

Vacuum tubes for Video Amplification: From the H.F. and L.F. considerations it is clear that the choise of vacuum tubes for video amplification is a function of the transconductance (g_m) of the tube and the capacity of the tube. The figure of merit of the tube is the ratio of transconductance (g_m) to the capacity (c) $\therefore$ Figure of merit = g_m/C (This criterion should be used with due care as the tube capacity includes the wiring capacity. So the gain depends to a lesser extent on the tube capacity.)

In the following table some of the tubes are listed with their figures of merit:

Type no.	Heater volts amp.	max. anode volts	Grid bias volts	Grid-plate transconductance µmhos	Amplification factor µ	Figure of merit g_m/c tube
			Triodes			
6C5	6.3 , 0.3	250	-8	2000	20	77
6J5	6.3, 0.3	250	-8	2600	20	108
6F8G(twin triod)	6.3, 0.6	250	-8	2600	20	95
955	6.3, 0.15	180	-5	2000	25	230

cities in the circuit are large. Sometimes large condensers possess a certain amount of inductance so it is required to shunt the equalizing condenser in the plate circuit and also the bias and screen by-pass condensers. So the mica condensers are used. (In our present case, the shunt-peaking is used, as it is the most advantageous one and is popularly used. It is know that the series-peaking circuit has a greater and constant gain and lesser time delay variation than that for shunt-peaking circuit; but the shunt-peaking circuit gives amplification at frequencies higher than top frequency F_{max}) while the other one does not.)

Vacuum tubes for Video Amplification: From the H.F. and L.F. considerations it is clear that the choice of vacuum tubes for video amplification is a function of the transconductance (g_m) of the tube and the capacity of the tube. The figure of merit of the tube is the ratio of transconductance (g_m) to the capacity (c) . Figure of merit = g_m/c (This criterion should be used with due care as the tube capacity includes the wiring capacity. So the gain depends to a lesser extent on the tube capacity.)

In the following table some of the tubes are listed with their figures of merit:

Type no.	Heater volts amp.	Anode volts	Grid bias volts	Grid-plate transconductance umhos	Amplification factor μ	Figure of merit g_m/c tube
		Triodes				
6C5	6.3 , 0.3	250	-8	2000	20	77
6J5	6.3, 0.3	250	-8	2600	20	108
6F8G(twin triod)	6.3, 0.6	250	-8	2600	20	95
955	6.3, 0.15	180	-5	2000	25	250

		Beam-power tetrodes				
6L6	6.3, 0.9	375	-17.5	6000	135	231
6V6	6.3, 0.45	250	-12.5	4100	2/8	178
6Y6G	6.3, 1.25	200	-13.5	7000	125	250
25L6	25, 0.3	110	-7.5	8200	82	315
807	6.3, 0.9	600	-30	6000	135	315
6AG7	6.3, 0.65	300	-10.5	7700	770	320
			Pentodes			
6AB7/1853	6.3, 0.45	300	-3.0	5000	3500	380
6AC7/1852	6.3, 0.45	300	-1.5	9000	6750	550
1851	6.3, 0.45	300	-1.5	9000	6750	560
1231	6.3	300	-2.5	5500	3850	400
1232	6.3	300	-2.0	4000	3000	350
954	6.3, 0.15	250	-3	1400	2000 +	234
956	6.3, 0.15	250	-3	1800	1440	290

(Ref. Principles of Television Engineering - Fink.)

Generally, the triodes are not used for video amplification because of their large total input capacitance required for a large gain. The Input capacity C in the case of triodes is $C = (C_{grid\text{-}ground} + C_{grid\text{-}plate}) \times$ Gain of the tube.
So 6C5 is generally excluded while considering video amplification tubes.

The rest of the tubes listed are good for video amplification. The tube R.C.A. 955 has a limited application as its capacity is quite high for high gain as in the case of triodes. The last three tubes listed in the table are the specially developed television tubes and they have surpassed the ordinary vacuum tubes (even R.C.A. 954 pentodes.) It is the best among the ordinary vacuum tubes used for television purposes.)

The following table indicates the better performance of a specially developed television tube by comparison with 6C6 and 954. Use is made of

$$G_{H.F} = \frac{R_L g_m}{\sqrt{1+(f/f_{max})^2}}$$ and f is so chosen that $\frac{f}{f_{max}} < 1$

$$\therefore G_{H.F.} = \frac{g_m}{2\pi f_{max} C_T} \qquad \therefore R_L = \frac{1}{2\pi C_T f_{max}}, \quad f_{max} = 4.5 \text{ m.c.p.s}$$

Type	C_T	$R\ \Omega$	Gain
6C6	16.5 μμf.	2, 100	2.5
954	11.0 μμf.	8, 200	3.5
1852	21. 0μμf.	1,400.	12.6

C_T = total capacity
= capacity from the last table + 5μμf (5μμf represents the wiring capacity)

(Reference : No. 1.)

D - C Reinsertion

A video signal when sent through a R - C coupled amplifier loses its DC component as the condenser prevents any D.C from passing. This D C component is the average value of the signal & represents for each scene the average background illumination. The AC varies above and below this average value, depending upon whether they represent elements that are darker or brighter than the background illumination. So with D C fixed, the black or grey or white or any other color is always reproduced by the same illumination. So if D C is removed, there is no information as to the absolute value of the color.

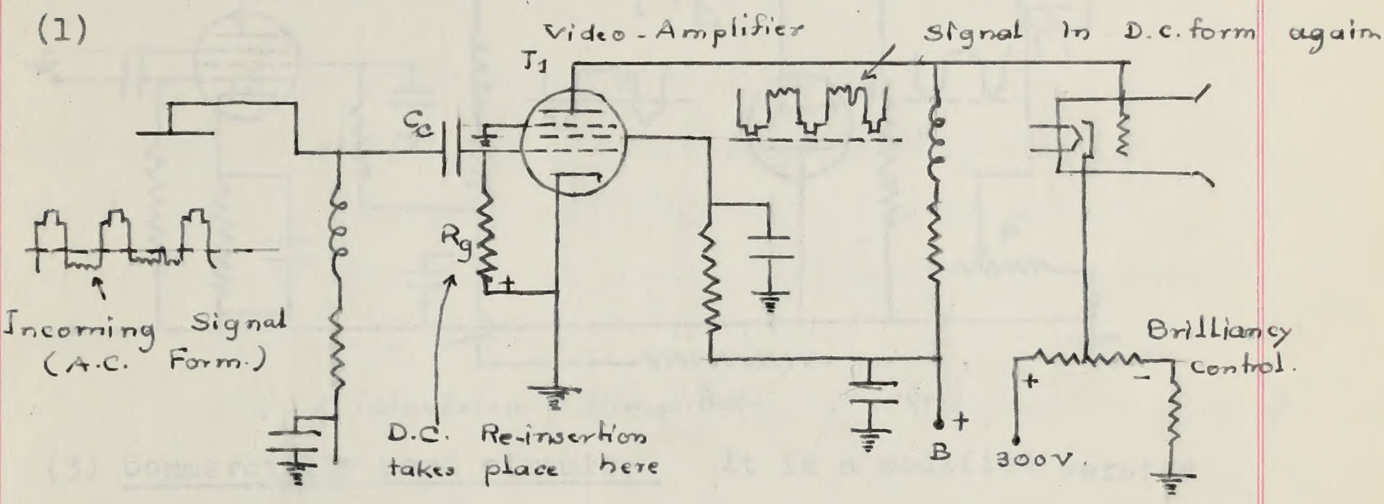
Finally, when the D C is present, the sync. and blanking signals have the same fixed level. But in the absence of the D.C. these pulses assume various levels, each requiring a different bias on the grid of the cathode ray tube in order to blank out the beam.

A cathode ray tube has a definite characteristic curve and for a certain input voltage a definite amount of light appears on the s creen. As all the blanking pulses are placed on the same level, the tube reacts to them in the same manner, throughout the entire reception of the signal so each color must produce the same illumination every time its corresponding voltage is applied to the C.R. tube. This is only possible if all video-signals have the same reference level. So the D C components have the importance.

Because of the reasons given above it is necessary

absolutely to have a D-C component present in the signal. The chief object behind the D-C re-insertion is to bring all the pulses to one common level. There are various methods of re-inserting the D-C:

(1)

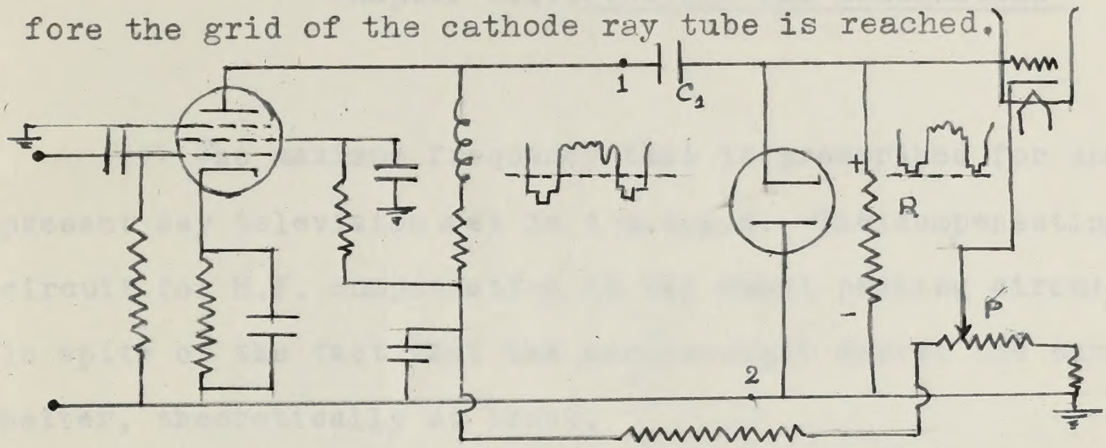


(Television Simplified- Kiver).

The simplest circuit is shown. Here the final video-amplifier is operating at zero fixed bias with no signal applied to the grid. As soon as the signal arrives, the grid current flows, its amount being a function of the strength of the signal voltage. The A-C voltage to be applied to the grid of this last video-amplifier should be of - ve phase in order to obtain a proper +ve phase at the output. This circuit brings back all the pulses to a fixed level, thereby all the signals are lined up again and are then applied to the cathode ray tube.

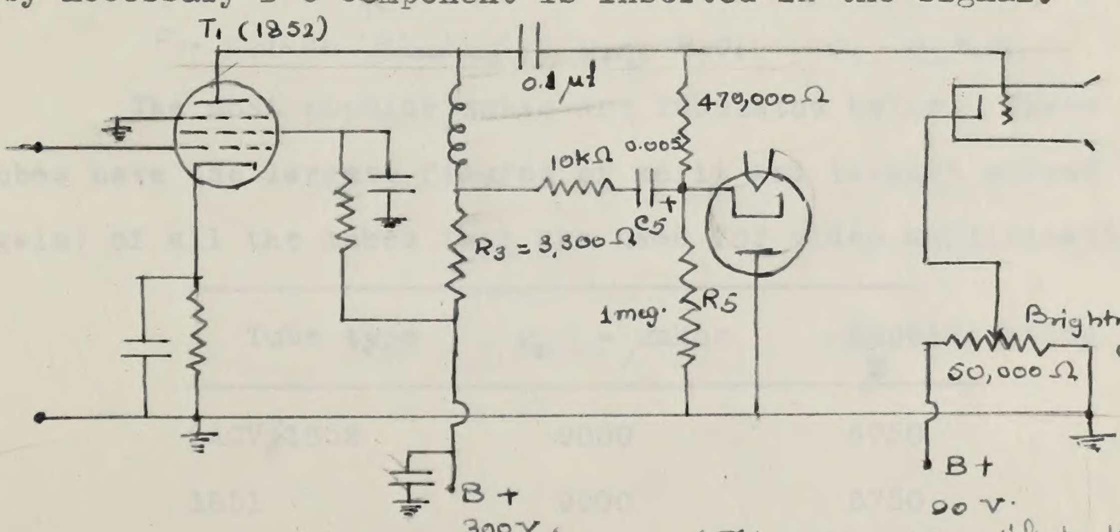
(2) D.C. Re-insertion with a Diode: It consists of an ad-ditional diode tube but the highly +ve voltage from the con-trol grid of the cathode ray tube is removed. The signal,

until it reaches the d c restorer, composed of a condenser C_1, a resistor R and the diode tube, has the A.C. form and has a positive phase as no further reversals take place before the grid of the cathode ray tube is reached.



(Television Simplified- Kiver.)

(3) <u>Commercially used circuit:</u> It is a modified version of the diode circuit used in R.C.A. television sets. As seen the diode is placed merely across the portion of plate output of T_1, obtained from the resistor R_3. The condenser C_5 charged to the peak value of the pulses, discharges through 1 mega. Ω resistor. The effect of C_5 charge is to place its stored voltage in series with the A C video signal, thereby necessary D C component is inserted in the signal.



(Television Simplified- Kiver.)

Chapter X....Findings and Conclusions

The maximum frequency that is prescribed for the present day television set is 4 m.c.p.s. The compensating circuit for H.F. compensation is the shunt peaking circuit, in spite of the fact that the series-shunt serves the purpose better, theoretically at least.

Kimball and Seeley have experimentally shown that the values of

$k_R = 0.85$, $k_L = 0.30$ serve the purpose better but the values $k_R = 1.0$, $k_L = 0.5$ are the popularly used ones in present day design work.

With these values of k_R and k_L the design equations are:

H.F. $R_L = 1/2\pi f_{max.} C_T$; $L_1 = 0.5 C_T R_L^2$

L.F. $R_{gl} C_c = R_L C_1$; $R_1 \geq 20 X_{C_1}$ (at the lowest f.)

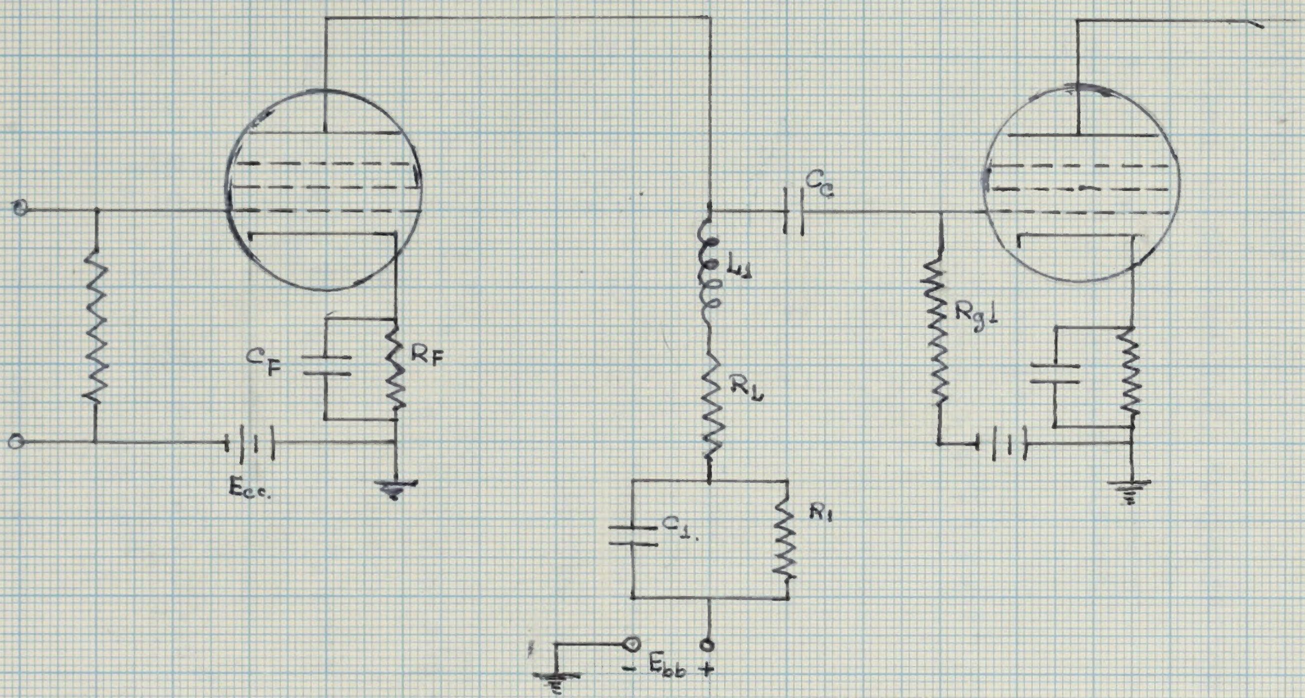
For Cathode Biasing : $R_F C_F = R_1 C_1$; $C_F = g_m R_L C_1$.

The most popular tubes are tabulated below. These tubes have the largest figures of merit and largest output (gain) of all the tubes that are used for video amplification.

Tube type	g_m - μmhos	Amplification μ
6AC7/1852	9000	6750
1851	9000	6750
1231	5500	3850

(Reference : No. 4.)

Diagram 36



6AC7 tube: $g_m = 9{,}000$ μmhos. $f_{max} = 4$ mcps.

$R_{gl} = 0.5$ megohms. Lowest frequency = 20 cps.

$C_c = 0.01$ μf.

$C_T = 25$ μμf.

$$R_L = \frac{1}{2\pi f_{max} C_T} = 1{,}600\ \Omega$$

$$L_1 = 0.5\, C_T R_L^2 = 32\ \mu hy.$$

$R_1 = 51{,}000\ \Omega$

$C_1 = 3.13$ μf.

$R_F = 3{,}548\ \Omega$.

$C_F = 45$ μf.

Design:

Data:

6AC.7/1851 tube

With this tube, $R_{g1} = 0.5$ mega ohm, serves the purpose satisfactorily and $C_c = 0.01 \mu f$ is chosen because of low frequency considerations.

Then using the H.F. compensation

$$R_L = \frac{1}{2\pi f_{max} C_T} = \frac{1}{2 \times 3.14 \times 4 \times 10^6 \times 25 \times 10^{-12}} \qquad \because C_T = 25 \mu\mu f.$$

$$= 1{,}600 \ \Omega$$

$$L_1 = 0.5 C_T R_L^2 = 0.5 \times 25 \times 10^{-12} \times (1{,}600)^2$$

$$= 32 \mu hy.$$

Now $\quad R_{g1} C_c = R_L C_1$

$$\therefore \ C_1 = 3.13 \mu f.$$

$\because \ R_1 \geq 20 X_{C_1}$ at the lowest frequency (20 c.p.s.) to be passed (Television Simplified – Kiver)

$$\therefore R_1 = 20 X_{C_1} = \frac{20}{2 \times 3.14 \times 20 \times 3.13 \times 10^{-6}}$$

$$= 51{,}000 \ \Omega$$

and $\because C_F = R_L g_m C_1 = 9{,}000 \times 10^{-6} \times 1{,}600 \times 3.13 \times 10^{-6}$

$$= 45 \mu f.$$

$$\therefore \ R_F = \frac{R_1 C_1}{C_F} = \frac{51{,}000 \times 3.13 \times 10^{-6}}{45 \times 10^{-6}}$$

$$= 3{,}548 \ \Omega.$$

$$\therefore R_F = 3{,}548 \ \Omega.$$

The Design Values:

$R_L = 1{,}600\,\Omega$

$L_1 = 32\ \mu hy$,

$R_1 = 51{,}000\,\Omega$,

$C_1 = 3.13\ \mu f$,

$R_f = 3{,}548\,\Omega$,

$C_f = 45\ \mu f$,

****

Chapter XI...Comprehensive Abstract of Thesis

This paper has pointed out the functioning of video amplifiers and their relation with other elements of a televission system. It is seen that the smooth working of a television system, depends upon the proper working of the video amplifiers over the complete range (30 c.p.s.) to (4 m.c.p.s.). The main conditions that a video amplifier should fulfill are

i) The frequency response should be constant over the entire range.

ii) The time delay should be constant or zero over the usable frequency range.

An uncompensated video stage generally does not satisfy these requirements so some compensation circuits are used. They help in reducing the timedelay variations and in keeping the gain constant over the entire frequency.

The discussion starts with an outline of the working of television and the process of scanning. The scanning is performed by means of a beam of electrons, the scanning pattern having any desired shape. This process of scanning is carried at both ends of the system, the transmitter and receiver, and for perfect reproduction these two patterns need be synchronous and identical with each other. In case of a flicker present in

the reproduction, interlaced scanning pattern helps in minimizing the disturbance in the reproduction.

As the process of scanning is carried out an electrical signal is generated. It is called the camera signal. This signal sometimes requires to be fed with additional pulses, the blanking and sync pulses, in order to supply the camera signal with the necessary optical information of the picture. Generally these signals are applied to the camera signal during the retrace period of the scanning beam.

The camera signal together with blanking signal and sync. pulses form a picture signal, the so-called video signal.

The camera signal mentioned above consists of two components: 1) D.C. 2) A.C. and they have two distinct performances toward the picture reproduction. The latter gives the information regarding brightness variations of the picture from average value, while the former furnishes the background details. The control of brightness of the picture is a function of the D.C. component of the camera signal, as is seen from the discussion.

Generally the output signal of a television system is checked for distortion by comparison with the standard waveforms 1) Square Wave

2) Ideal Saw-Tooth

3) Non-Ideal Saw-Tooth

But sometimes the output is non-periodic and as these are periodic waveforms, they cannot be used for comparison purpose. In such cases Transient Response criterion is used. The method,

used by Bedford &fredenhall is the most advantageous of the three discusse-d.

the wave-form distortions that are generally met with are classified as follows:

I)Distortions due to non-ideal phase & amplitude characteristics.

2)Distortions due to presence of masking voltage, (tube noise.)

3)Distortions that are purposely introduced to improve the quality of the picture.

The first type of distortions are further classified according to whether they are due to non-ideal amplitude characteristic or due to both the characteristic(non-ideal).The distortion due to non-ideal ampltude characteristic is known as "the Symmetrical distortion" & the other type " the Non-symmetrical distortion." Both these distortions are accounted for by H.A.Wheeler on the basis o of the paired echoes.

Of the tube noises,the Shot effect noise is the most troublesome.It is not as serious a matter in storage type tubes as in the non-storage tubes.In such tubes ,it is reduced by the use of "Electron Multiplier tubes".The electron multipliers increase the number of electrons,thereby the electron flow-therefore-the current-is made smooth.So the current fluctuations are very much minimised.As the number of electrons is increased the signal to noise ratio is correspondingly increased,thereby the noise is reduced.The noise(voltage) is given by:

$$e_{r.m.s.} = 5.64\times IO^{-IO} Z\sqrt{I(f_1 - f_2)}$$

So if the frequency is increased , the Shot effect noise increases & it puts a restriction on the f_{max} that should be used.

It is clear from the video signal discussion that the larger the frequency range used ,the better is the reproduction.So for a better reproduction f_{max} should be quite high.(Shot effect noise should be considered in extending f_{max}.)

The main object of the video amplifiers is to keep the gain & phase shift constant over the entire range.As the uncompensated stage is unable to satisfy these requirements some compensating circuits are used.Of the three compensating circuits discussed the series-shunt circuit serves the purpose best.At present, in spite of increased gain & smalltime-delay variations of the Series Shunt circuit , shunt circuit is used as it makes possible ,work beyond f_{max} utilised.

The L.F.compensation is controlled by the $R_I C_{I_C}$ combination. These H.F.&L.F.compensation circuits function independently of eachother.

From the overall considerations it is found that large number of stages are sometimes necessary because of reduced gain per stage due to the bandwidth.(The number of stages to be used is a function of the f_{max} to be amplified.)Besides if the two compensating circuits are combined in the indicated ,the response is further improved.

(The modern television tubes

6AC7.............Figure of merit 562.
6AB7.............Figure of merit 385.
6AG7.............Figure of merit 385.

serve the purpose better than theolder type vacuum tubes.)

(Reference : No. 6)

So if the frequency is increased, the shot effect noise increases & it puts a restriction on the f_{max} that should be used.

It is clear from the video signal discussion that the larger the frequency range used, the better is the reproduction. So for a better reproduction f_{max} should be quite high. (Shot effect noise should be considered in extending f_{max}.)

The main object of the video amplifiers is to keep the gain & phase shift constant over the entire range. As the uncompensated stage is unable to satisfy these requirements some compensating circuits are used. Of the three compensating circuits discussed the series-shunt circuit serves the purpose best. At present, in spite of increased gain & small time-delay variations of the series shunt circuit, shunt circuit is used as it makes possible work beyond f_{max} utilised.

The L.F. compensation is controlled by the $R_f C_f$ combination. These H.F. & L.F. compensation circuits function independently of eachother.

From the overall considerations it is found that large number of stages are sometimes necessary because of reduced gain per stage due to the bandwidth. (The number of stages to be used is a function of the f_{max} to be amplified.) Besides if the two compensating circuits are combined in the indicated, the response is further improved.

(The modern television tubes

6AC7..............Figure of merit 509.
6AK7..............Figure of merit 286.
6AG7..............Figure of merit 330.

serve the purpose better than the older type vacuum tubes.)

Reference 129. 6

In the discussion of video amplification account must be taken of the cicuits employed to connect two amplifiers separated from eachother.The universally applied circuits for this purpose are the Co-Axial cables.It consists of acentral conductor running through the centre of the cylindrical sheath,which acts as the other condector.

The quantities 1) Surge(Characteristic) impedance offered by the line to the voltages applied to it,11)attenuation of the signal,applied,by the losses in the conductors& insulation,and 111)the time delay(phase-frequency responce) due to reactive effect,best describe the cables.These quanties,in turn,are functions of the Induction(L),Capacitance(C),Resistance(R),the sum of the inner and the outer conductor;& the Conductance(G);all per unit length of the cable.

(The surge impedance(Z_0) is: $Z_0 = \sqrt{\frac{R+jwL}{G+jwC}}$ ohms.

In case R & Gare much smaller w.r.to jwL & jwC,then $Z_0 = \sqrt{\frac{L}{C}}$ ohms.

Z_0 is also obtained from $Z_0 = 138.5\log_{10}\frac{d_0}{d_1}$,where d_0 is the inside diameter of the outer conductor,& d_1 is the diameter of the inner conductor.)

The attenuation A is: $A = 4.346\, R\sqrt{\frac{L}{C}}$ db per unit length.

$= \frac{0.031R}{\log_{10}\left(\frac{\sqrt{}d_0}{d_1}\right)}$;

& the time delay is: $t = \sqrt{LC}$ per unit length,

= time required ti transmit energy from one end to the other of the line.

From the expression for the time delay it is clear that it is quite independent of the frequency(within wide limits).So the coaxial cables are best suited for the video signal transmission.)

(Reference :- No. 4.).

If the line is terminated in an impedance not equal to the surge impendane, reflections may occur at the terminal of the cable; & these reflections become serious if the cable length is an appreciable fraction of the wavelength. Such reflections give rise to "Ghost images". In order, therefore, to reduce these reflected images the two impedances must be properly matched.

In 1927, television transmission was demonstrated between Washington and New-York(225 miles) using 20k.c. band over an open wire line. In 1937, there was a similar demonstration between New-York and Philadelphia using a 1 Mc. band over an experimental co-axial cable which was looped to provide a total circuit length of 180 miles. Many other tests and demonstrations have been carried out.

In 1945 and 1946, techniques for handling television pick ups and switching, paralleling in many respects the methods used in the sound - programme transmission field, were sufficiently advanced to be demonstrated on many occasions. Experimental television transmission over the coaxial by several broadcasters is now continuing on a regular schedule. In 1946 color television was sent over the coaxial from New York to Washington and back.

Recently, Boston to New-York television system was started, it uses four frequencies in the 3700 to 4200 band. These frequencies are utilised with incoming & outgoing carrier frequencies, differing by 40m.c. at each repeater to avoid crosstalk.

Between Boston & New-York there were seven sub-stations used, each station having broad band horn antennas with metal foc-

(Reference : P.I.R.E. Nov. 1947, No. 4)

cussing lenses are used. Each receiving antenna has two input frequencies, one for regular channel and one for a standby channel, signal separation being achieved by new types of filter sections inserted in the wave guides. Each repeater station has four antennas, two facing the route towards New York and two facing the route toward Boston. Each antenna has a mouth 10 ft. sq., horn length 10 ft., and a gain of 10,000 or 40 db. So the relay operation is made possible under all possible weather conditions, with a transmitter power of less than 1 watt. (Beam width of the horn antennas is only 2 degrees).

In between Boston and New York there are seven hilltop stations each having four repeaters, one for use and one for standby in either direction. Each of these repeaters, is a broad band amplifier capable of handling a bandwidth up to 5 m.c. with a gain constant within o.1 db. over the entire 10 m.c. bandwidth, characteristic of the repeater. For the present, the frequency modulation has a total swing of 4 m.c. So it is possible to run the high level amplifier stages near their overload points, at max. output.

The block diagram of the basic circuit used for transmitting terminals is shown below.

65 m.c. an f.m. picture signal output of the fm. oscillator limiter amplifier unit is fed into the balanced modulator along with a 3,865 m.c. local oscillator signal to obtain the desired 3,930 m.c.carrier signal.This is boosted 23 db.in level by

the micro-wave amplifier containing four type WE 402-A two gap vel. modulation amplifiertubes of the Samuel type,with the output of the last tube between 0.5 and 1.1 watts on a frequency of 3,930 m.c. (the 3,865 m.c. local oscillator frequency is generated by the reflex Klystron of the Shepherd Pierce type.)

The 3,930m.c. signal from the receiving antennae comes down a waveguide to a branching filter.(Y-Shaped)This filter accepts the correct signal & rejects the signal 4,200m.c.(4,130 in e our present case.), which is coming down the waveguide for stand-by channel.

The correct 3,930 m.c. input signal reaches a balanced modulator.T-he oscillator signal is obtained fromother balanced modulator by a 40 m.c.crystal oscillator & by a 3,905 m.c. Klystron oscillator and frequency stabilising circuit.So the result is 65 m.c. i-f input.This undergoes two stages of amplification in a unit at the end of the waveguide.

From here the signal goes to the main i-f amplifier via a co-axial cable and thence to a balanced modulator that is fed by the 3,905 m.c. micro-wave oscillator to obtain the desired 3,970 m.c. output carrier frequency -just 40 m.c. higher than the input carrier frequency.

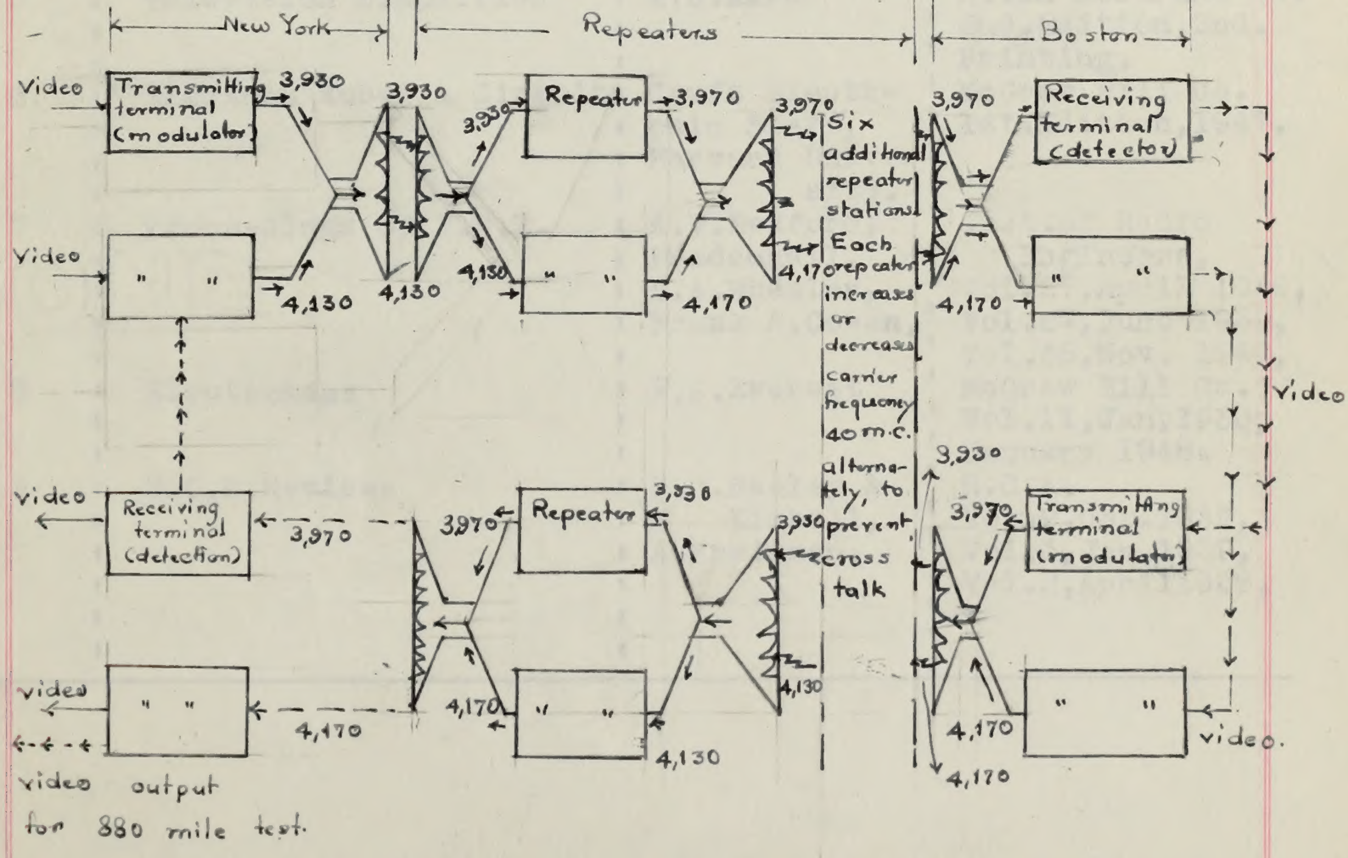
The local micro-wave oscillator frequency is thus cancelled as an error source;because the 40 m.c. crystal oscillator offer frequency accuracy far better thanis needed;the cummulative frquency error in the relay system is zero

At Boston receiving terminal the video frequency values

are as indicated in th-e diagram. For this experiment, the sound portions of the television progam are transmitted by the land wires.

As the time delay differences for different frequencies in the band transmitted are cummulative for the seven relay stations, equalization of the delay was required. The final system has been equalized to within 50 milli-microsecs. for all frequencies in the 5 m.c. bandwidth handled. (this is very much less than the time of one picture elements and is therefore not a serious cause of picture distortion).

The present day prescribed highest frequency for television purposes is 4 m.c.p.s.



N.Y. - Boston Micro-Wave Relay, providing two video channels in each direction. (Electronics - Jan 1948.)

"Bibliography"

No.	Title	Author	Publisher, Year.
1	Television	V.K.Zworykin, G.A.Morton,	John Wiley& Sons N.Y. 4th.Printing,1946
2	Radio Engineer's Handbook	F.E.Terman,	McGraw Hill Book Co. N.Y. 1st.Edition,5th. impression,1943.
3	Radio Engineering Handbook	Keith Henney,	McGraw Hill Co. N.Y. 3rd Edition,1941.
4	Principles of Television Engineering	D.G.Fink,	McGraw Hill Co. 1st.Edition,11th impression. 1947
5	Television Simplified	M.S.Kiver	D.Van Nostrand Co. 2nd.Edition,2nd. Printing.
6	Electronic tubes & Circuits	Cruft Electronic Staff, Harvard University.	McGraw Hill Co. 1st.Edition,1947.
7	Proceedings of I.R.E.	A.V.Bedford, Fredenhall, H.A.Wheeler, Frank A.Cowan,	Inst.of Radio Engineers, Vol.27,April 1939, Vol.27,June 1939, Vol.35,Nov. 1947,
8	Electronics	F,A.Everest	McGraw Hill Co. Vol.11,Jan,1938, January 1948.
9	R.C.A.Reviews	S.W.Seeley & Kimball, A.Preisman.	R.C.A. Vol.2,Oct.1937, Vol.3,Jan.1939, Vol.2,April1938.